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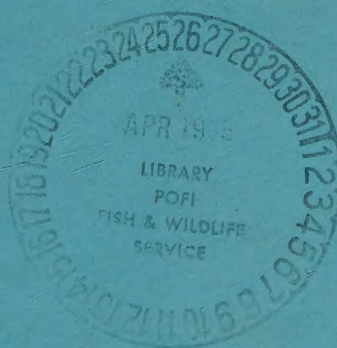
Marine Research

1952

No. 2

**The Chætognatha and other Zooplankton
of the Scottish Area and their value as
Biological Indicators of Hydrographical
Conditions**

By J. H. FRASER, M.Sc., Ph.D., F.R.S.E.



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SCOTTISH CHÆTOGNATHA

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ERRATUM

The chart on page 35 should appear on page 42 and the chart on page 42 should appear on page 35. The chart numbers and legends are correct as printed.

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The Chætognatha and other Zooplankton of the Scottish Area and their Value as Biological Indicators of Hydrographical Conditions

ABSTRACT

The Chætognatha are a useful group of plankton indicators in the North Atlantic as the various species found there are each associated with a particular type of environment. Methods of identification are given with a double set of photographic illustrations, one giving the general natural appearance of the species when preserved in formalin and the other a duplicate retouched to emphasise the diagnostic features.

The distribution of the Chætognatha in the area investigated by Scottish research vessels from 1936-1939 and 1946-1950 is charted and discussed in relation to the hydrography of the area and the distribution of other planktonic indicator species. As an example of the value of the plankton indicator methods in specific problems, the hydrography of the Fair Isle Passage is discussed.

INTRODUCTION

It is now over twenty years since Professor Meek (1928) correlated the occurrence of *Sagitta setosa* and *Sagitta elegans* with the hydrographical conditions of the Northumbrian coast. *S. setosa*, typical of indigenous North Sea water, is only rarely found in the inshore waters of the east Scottish coast, while *S. elegans* is rare close to the south English coast, so that the Northumbrian coast, between these two, is a particularly suitable site for this study. Professor Meek was able to demonstrate that when the southern North Sea water flooded the area *S. setosa* was dominant, but when the northern North Sea water with its Atlantic content replaced the southern North Sea water then *S. elegans* dominated. Prior to this Huntsman (1919) and Bigelow (1926) had worked on similar lines on the eastern American coast and Ritter-Zahony and others working on the taxonomy of Chætognatha had commented on the occurrence of different species with different habitats. Since Professor Meek's work much has been done both in Britain and other countries to further such observations, e.g. Mackintosh (1934), Russell (1935 a. and b. and 1939), Furnestin (1938), Redfield and Beale (1940), Fraser (1937 and 1949), Marshall (1948), and Moore (1949), to quote only a few, and it has now been established that the various species of Chætognatha are associated each with a more or less specific hydrographical environment, making the group one of the foremost of the biological indicators.

The area around Scotland affords a specially fertile field for such a study because of the many and varied hydrographical conditions which are found, due largely to the fluctuations of the North Atlantic Drift along the western seaboard and its varied penetration into the North Sea; and also to the influence of Arctic currents and the big depth range from the shallow North Sea to the deeps in the Faroe-Shetland Channel and off the west Scottish coast. Since 1935 (the war years excepted) the Chætognatha in the plankton taken by Scottish research vessels have been specifically identified and details of their distribution kept. It is therefore possible to compare these distributions from year to year and to correlate the changes with changes in the environment.

NOTES ON THE IDENTIFICATION AND GENERAL HABITAT OF THE SPECIES

To be useful biological indicators, organisms should be easily identified, preferably by the naked eye and on the spot, and to this end descriptions are given here of the various species found as they appear in plankton when preserved in formalin. Many of the textbook characters used to distinguish the species, such as the number of teeth, serrations on jaws, the corona and percentage lengths of fins, are difficult to see without recourse to microscopic examination or other technical treatment, but after some experience it is found, as in most other identifications in biological fields, that it is not usually necessary to use many of the textbook characters. It is hoped that these descriptions will simplify making quick but reliable identifications. Brief notes on the diagnostic characters are included as a check but these

are not intended to be exhaustive, and for further details of taxonomy and synonymy, reference should be made to the standard monographs on the subject. Staining should not normally be necessary but can be useful, especially when examining the details of fins and corona. For these purposes staining should be as brief as possible so that only the outermost tissues become stained, further staining only obscures these features. The fins may usually be seen simply by removing the animal from the liquid, when the wet fins show up clearly, though they are too transparent to be seen when immersed. Alcohol should not be used for preservation because the bodies shrink and it then becomes almost impossible to make out the points of origin of the fins. Rigidity is a useful determining factor but is one that is difficult to define because it is effected by size and state of preservation. Roughly speaking, a specimen which does not droop down on either side when picked up by the middle with a pair of forceps is rigid. If, however, the two sides hang down it is termed flaccid.

A character investigated by Tokioka (1950) is the size and shape of the total area of the eye and of the pigment fleck within that area. He contends that the size of the eyes and eye pigment in proportion to the length of the body increases with age, and is greater in small than in large species; and that the relationship between the eye pigment and the total area of the eye is specific as also is the shape of the pigment fleck. This, he says, can actually be used as a means of separating imperfectly preserved specimens of *S. regularis* and *S. neglecta*. Tokioka also deduces that there is a tendency for eye pigment to degenerate in mesoplanktonic, and to disappear in bathyplanktonic species. His paper is confined to those Chætognaths taken in Japanese waters and several of the north European species are not therefore included.

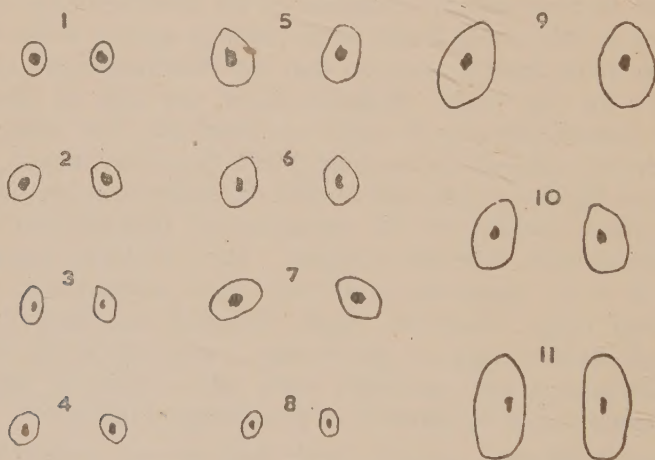


FIG. 1

The eyes of various species of Chætognaths showing the proportion of the pigment fleck to the total area of the eye. The shape of both outline and pigment are individually variable.
 1. *S. setosa*; 2. *S. elegans*; 3. *S. serratodentata*; 4. *S. bipunctata*;
 5. *S. lyra*; 6. *S. hexaptera*; 7. *S. enflata*; 8. *K. subtilis*; 9. *S. maxima*;
 10. *S. planctonis*; 11. *E. fowleri*; (*E. hamata* and *S. macrocephala* have no pigment).

An examination of these points in specimens from the Scottish plankton would suggest that the shape and size of the eye could be used as an aid to identification of poorly preserved specimens within certain limits only. The actual shape of the pigment flecks and the hyaline cells around them varies considerably from one individual to another, and so also does the shape of the outline of the eye which is often difficult to see and may be round, oval or drop shaped. Their relative proportions are certainly less variable. The absence of eye pigment in *Eukrohnia hamata* would separate that species from *E. fowleri* or from any other species of Chætognath with which it might be confused when poorly preserved. *S. macrocephala* has no eye pigment but is not likely to be mistaken. The very small eye and pigment fleck of *S. serratodentata* could well be used to separate that species from *S. elegans* and *S. setosa*, and indeed from most others likely to be found

in this area, except perhaps *K. subtilis*, but the serrations on the jaws could be used with greater certainty and with no greater difficulty. The eyes of *S. elegans* can only doubtfully be separated from those of *S. setosa* though the total area of the latter tends to be smaller and it has a proportionately larger fleck. The large eye with relatively small fleck of *S. planctonis* and *E. fowleri* might serve to separate them from *S. elegans*.

Figures of the eyes of eleven species with pigmented eyes found in a Scottish area are given (Text Fig. 1) but their use as an aid to identification should be unnecessary except in specimens which have lost their normal form, although it must be remembered that there is considerable individual variation.

Sagitta setosa Müller 1847. Plate I, Figs. 1A and B

This is the species Meek found to be associated with the indigenous North Sea water and it is commonly associated with water of salinities of less than 35‰ such as are found in the North Sea, Irish Sea, etc.; Furnestin (1938) found it in the Gulf of Gascogne and it occurs in the Adriatic (Scaccini and Ghirardelli, 1941b) and in the Baie de Villefranche (Ghirardelli, 1950). It appears to be confined to European seas, whereas all the other species dealt with in this paper are found, in suitable habitats, on both sides of the Atlantic, and many of them in all the oceans of the world. Normally a shallow water species, *S. setosa* can be carried out over deep water such as the Norwegian Deeps by surface currents.

APPEARANCE

Small, rigid but very transparent. When viewed dorsoventrally on a dark background the gut can clearly be seen to emerge from the head and to continue down the body as a fine white thread. The ovaries, when present, are very short ovoid white bodies immediately in front of the tail septum. There is no well-marked neck region.

CHARACTERS

<i>Anterior fin</i> :	Starts at some distance behind the ventral ganglion.	<i>Vesiculæ seminales</i> :	Close to posterior fin and separated from the tail fin by about half their own length.
<i>Posterior fin</i> :	More on body than on tail.	<i>Ovaries</i> :	Short and ovoid.
<i>Tail</i> :	16 to 25% of the body length, excluding the tail fin.	<i>Collarette</i> :	Usually small or sometimes missing.
<i>Anterior teeth</i> :	Usually <8.	<i>Corona</i> :	Begins between the eyes and extends well on to the body.
<i>Posterior teeth</i> :	Up to 16.	<i>Gut diverticulæ</i> :	Absent.
<i>Hooks</i> :	8 (9).	<i>Length</i> :	Rarely more than 14 mm.

Sagitta elegans elegans Verrill 1873. Plate I, Figs. 2A and B

A coastal form associated with oceanic influence. It is found on both sides of the Atlantic, and also in parts of the Pacific.

APPEARANCE

Rigid and somewhat milky white, varying from almost transparent when young to almost opaque white when older. When viewed on a dark ground the emergence of the gut from the head cannot be seen and the gut never appears as a thin white thread as in *S. setosa*. The ovaries when present are elongated bodies extending forward from the tail septum but they are not usually visible unless well developed owing to the opacity caused by the musculature of the body. There is a well-marked neck region which in side view is often curved away from the dorsal side but with the head turned up dorsally to the body axis.

CHARACTERS

<i>Anterior fin</i> :	Begins well behind the ventral ganglion.	<i>Ovaries</i> :	Elongated and when mature can extend to about one-third of the body length.
<i>Posterior fin</i> :	Two-thirds on body.	<i>Collarette</i> :	Present, generally small but in large wintering specimens it can become enlarged.
<i>Tail</i> :	17 to 25%.	<i>Corona</i> :	Begins close to eyes and extends well on to the body.
<i>Anterior teeth</i> :	<8.	<i>Gut diverticulæ</i> :	Present.
<i>Posterior teeth</i> :	<18.	<i>Length</i> :	Up to 30 mm.
<i>Hooks</i> :	10 to 11.		
<i>Vesiculæ seminales</i> :	Conical, close to tail fin and separated from posterior fin.		

There are two other varieties of *S. elegans* found in the area:—

Sagitta elegans arctica Aurv.

This sub-species has a boreal-arctic distribution. It matures at a much larger size (over 40 mm.) and has usually more teeth and longer ovaries than *S. elegans elegans*.

Sagitta elegans baltica R.Z.

This is the Baltic form which has a shorter tail, smaller anterior fin and corona.

Sagitta serratodentata Krohn. Plate I, Figs. 3A and B

This is the most common oceanic species found in north European waters, where it is a surface (upper 200 m.) form, but it is also found in all the oceans of the world.

APPEARANCE

A very rigid and narrow species with a small head. It is opaque, often a chalky white or yellowish white when mature; the opaque ovaries extending well forward into the body. The vesiculæ seminales stand out as horn-shaped structures near the tail and are evident in quite small individuals, making them one of the best characters for quick identification.

CHARACTERS

Anterior fin: Begins just behind the ventral ganglion and extends close to, or is even confluent with the posterior fin. It is incompletely rayed at the front end and inner edges.

Posterior fin: Extends back as far as vesiculæ seminales.

Tail: 22 to 30%.

Anterior teeth: 7 to 10 (rarely 11).

Posterior teeth: <22, usually 10–19.

Hooks: 6 to 7, (9). The serrations on the hooks can be seen only with a microscope, in clear cases the 16 mm. objective is adequate but a 4 mm. lens may have to be used as the serrations may be much reduced, sometimes even to minute knobs.

Vesiculæ seminales: Very prominent, touching both tail fin and posterior fin.

Ovaries: Very long, often extending forward as far, or even beyond, the ventral ganglion.

Collarette: Very small, or small in fully mature specimens.

Corona: Long and sinuous, beginning between the eyes.

Gut diverticulæ: Absent.

Length: To about 17 mm.

Thomson (1947) sub-divides this species into three sub-species; *S.s. pacifica*, *S.s. atlantica* and *S.s. tasmanica*, basing the division on the form of the mature seminal vesicles together with a number of associated but overlapping characters. If this division is acceptable, the Scottish material contains a mixture of all three—chiefly perhaps *S.s. tasmanica*—but with variations that would suggest other sub-divisions also. In view of the diversity of form in the vesicles, fins, jaw serrations, etc., I do not think the differences described by Thomson are sufficient to warrant division into separate sub-species, and I therefore use the term *S. serratodentata* here to include all such variations. Ghirardelli (1950) considers such variations to be environmental.

Sagitta maxima Conant. Plate II, Fig. 6

This is a cold deep water species.

APPEARANCE

It is large, very transparent and flaccid. The gut stands out as a whitish ribbon. The head is broader than long. The anterior and posterior fins are confluent and begin at or in front of the ventral ganglion. Immature specimens up to about 30 mm. in length are the most commonly occurring size when found in this area. Much larger individuals (occasionally up to more than 90 mm.) are sometimes found.

CHARACTERS

Anterior fin: Begins beside or in front of the ventral ganglion and is confluent with the posterior fin which is somewhat three-cornered and is broadest behind the tail septum.

Vesiculæ seminales: Ovoid, close to posterior fin.

Ovaries: Long and thread-like when mature.

Collarette: Absent.

Tail: 19 to 25%, broad.
Anterior teeth: 5 or 6.
Posterior teeth: <8.
Hooks: About 11.

Corona: Short and pear-shaped, beginning beside the eyes and scarcely extending on to the body.
Length: May reach more than 90 mm.

Sagitta lyra Krohn. Plate II, Fig. 7

Moderately deep oceanic species of warm origin.

APPEARANCE

Fairly large, very transparent species. Not easily distinguished from *S. maxima* on casual examination, but head is not so broad and the tail is narrower than in that species. The best character used to separate the two is that in *S. lyra* the anterior fin begins appreciably behind the ventral ganglion, whereas in *S. maxima* it begins at, or in front of, the ventral ganglion. These differences can usually be seen on examination with a lens or by lifting the specimen out of the water when the outlines of the fin can be fairly easily distinguished. It rarely exceeds 35 mm. in length and specimens of this type taken in north European waters between 35 and 90 mm. are most likely to be *S. maxima*. The southern variety of *S. lyra* often referred to as *Sagitta gazella* may reach 70 mm.

CHARACTERS

Anterior fin: Begins appreciably behind the ganglion and is confluent with the posterior fin.
Tail: 14 to 18%.
Anterior teeth: <8, usually 4 to 6.
Posterior teeth: <12, usually 6 to 10.
Hooks: 7 to 8 (occasionally up to 9).
Vesiculæ seminales: Separated from both the posterior and tail fin, but nearest posterior fin.

Ovaries: Long and thin.
Collarette: Absent.
Corona: Pear-shaped, beginning behind the eyes and scarcely extending on to the body.
Gut diverticulæ: Absent.
Length: Up to about 35 mm.

Sagitta planctonis Steinhaus. Plate II, Fig. 9

A very deep water species. (Though Moore (1949) states that it is a surface form in the Bermuda area.)

APPEARANCE

Very rigid. Milky white to quite opaque. Somewhat resembling *S. elegans* but much stronger and sturdier and with a prominent head and collarette, and a stout tail region.

CHARACTERS

Anterior fin: Rayless at the front and inner edge and begins at the level of the ganglion.
Posterior fin: With an inner rayless zone.
Tail: 20 to 26%, stout.
Anterior teeth: Up to 11, usually 6-8.
Posterior teeth: Up to 22, usually 15-18.
Hooks: 8 to 9 (10).

Vesiculæ seminales: Elongated and conical near the tail fin.
Ovaries: Very long when mature.
Collarette: Very prominent and more or less uniformly thick from the head to the anterior fin.
Corona: Begins in the neck region where it is pointed and extends half-way to the ganglion.
Gut diverticulæ: Present.
Length: Up to 40 mm.

Sagitta hexaptera Orb. Plate II, Fig. 5

A warm mid-water species.

APPEARANCE

Large, very transparent, and in the older stages flaccid. The body is narrower than most other transparent species and the very small anterior fin is at about the middle point of the total length.

CHARACTERS

Anterior fin: Very small and rounded. Very considerably behind the ventral ganglion.
Posterior fin: Small and well separated from the anterior fin. Both fins with inner rayless zones.

Vesiculæ seminales: Rounded knobs near the tail and well separated from the posterior fin.
Ovaries: Long, reaching the neck region when mature.

<i>Tail:</i>	16 to 22%.	<i>Collarette:</i>	Absent.
<i>Anterior teeth:</i>	Usually 3.	<i>Corona:</i>	Pear-shaped, beginning beside the eyes and extending to the neck.
<i>Posterior teeth:</i>	Rarely more than 6, usually 4 or 5.	<i>Gut diverticulæ:</i>	Absent.
<i>Hooks:</i>	7 to 8 (10).	<i>Length:</i>	Up to 60 mm.

Sagitta macrocephala Fowler. Plate II, Fig. 10

A warm, very deep water species.

APPEARANCE

This is an unmistakable species. It usually has an opaque body with a long colourless transparent tail region and the gut is bright reddish or orange. It has a very large elongated head armed with an unusually prominent set of hooks. As seen in plankton collections it almost always has a number of kinks in the body giving it a most untidy appearance.

CHARACTERS

<i>Anterior fin:</i>	Small and starts well behind the ganglion.	<i>Hooks:</i>	10 to 12.
<i>Posterior fin:</i>	Much bigger than the anterior fin and has an inner rayless zone.	<i>Eyes:</i>	Without pigment.
<i>Tail:</i>	30 to 34%.	<i>Vesiculæ seminales:</i>	Near the tail fin and separated from the posterior fin.
<i>Anterior teeth:</i>	6 to 10.	<i>Ovaries:</i>	Long and thick.
<i>Posterior teeth:</i>	20 to 38.	<i>Collarette:</i>	Absent.
		<i>Gut diverticulæ:</i>	Absent.
		<i>Length:</i>	Up to 20 mm.

Sagitta bipunctata Q. and G. Plate III, Fig. 11

This is a small surface oceanic form which is only very rarely found in the Scottish collections. It is between *S. setosa* and *S. elegans* in general appearance and has often been confused with either or both, resulting in a general impression that *S. bipunctata* is more abundant in the north European area than, in fact, it is. Separate notes on the identification and validity of this and closely allied species are given on page 13.

Eukrohnia hamata Möbius. Plate I, Figs. 4A and B

In boreal waters it is found at all depths but is found associated only with cold deep water in more temperate zones.

APPEARANCE

Rigid and more or less opaque, almost always with a distinct yellow or orange oil globule in the gut; it is usually of a somewhat untidy appearance when in formalin. The gut can be seen to emerge from the head in the form of a sinuous thread for the first few millimetres, after which it becomes straight.

CHARACTERS

<i>Lateral fins:</i>	Begin beside the ventral ganglion and become gradually broader towards the tail septum.	<i>Vesiculæ seminales:</i>	Separated from the posterior fin.
<i>Tail:</i>	19 to 31% but usually between 20 and 23%.	<i>Ovaries:</i>	Moderately long.
	One set of teeth up to 25.	<i>Collarette:</i>	Absent.
<i>Hooks:</i>	8 to 9.	<i>Corona:</i>	Small, flask-shaped; pointed in front and about the same length as the head and situated in the neck region.
<i>Eyes:</i>	Without pigment.	<i>Gut diverticulæ:</i>	Absent.
		<i>Length:</i>	Up to 43 mm.

Eukrohnia fowleri R.Z. Plate III, Fig. 14

Warm deep water. In Thomson's (1947) opinion, this species is only a warm water variety of *E. hamata*. I have found both types in the same collections with no intermediate forms, and I believe Ritter-Zahony to be correct in separating the two as different species.

APPEARANCE

The large head is attached to a long narrow neck which gradually broadens out into the body which is broadest at the tail septum. The gut stands out as a bright orange or red ribbon and I have never seen an

oil globule present. In plankton collections the head often becomes separated from the body, especially in older stages.

CHARACTERS

<i>Lateral fins:</i>	As in <i>E. hamata</i> .	<i>Eyes:</i>	Pigmented, rather close together.
<i>Tail:</i>	22 to 27%.	<i>Collarette:</i>	Absent.
<i>Teeth:</i>	Up to 30.	<i>Gut diverticulæ:</i>	Absent.
<i>Hooks:</i>	10 to 13.	<i>Length:</i>	Up to 40 mm.
<i>Corona:</i>	Pear-shaped, reaching to the neck.		

Krohnitta subtilis Grassi. Plate III, Fig. 15

Associated with warm water; in this area usually in the upper layers over deep water.

APPEARANCE

A very small, thin, transparent species. It has very long tail about one-third of the total length, which is good character to effect immediate separation from young stages of larger Chætognaths in the collection.

CHARACTERS

The single lateral fin is broad and about two-thirds on the tail.	<i>Vesiculæ seminales:</i> Relatively large, touching both tail and posterior fins.
<i>Tail:</i> 30 to 40%.	<i>Ovaries:</i> Club-shaped and very small.
<i>Teeth:</i> 11-16, very prominent.	<i>Collarette:</i> Absent.
<i>Hooks:</i> 7 to 10.	<i>Gut diverticulæ:</i> Absent.
<i>Corona:</i> Diamond-shaped, in the neck region.	<i>Length:</i> Up to 16.5 mm.

Spadella cephaloptera W. Busch

This is a bottom living form and is therefore not considered here.

In addition to the above species taken in the Scottish samples, the following may be expected to be found on occasion in localities where waters from the Azores or Biscayan region has penetrated.

S. decipiens Fowler

A slender but not very rigid species with very long anterior fins. *Vesiculæ seminales* well separated from the posterior fin. *Gut diverticulæ* are present and the corona begins in the neck region.

Sagitta enflata Grassi. Plate II, Fig. 8

A transparent tumid species with short anterior fins. The *vesiculæ seminales* are very small round knobs near the tail fin.

Sagitta friderici R.Z. Plate III, Fig. 12

A small rigid species like *S. bipunctata* but with *vesiculæ seminales* close to both posterior and tail fins. (See notes on *S. bipunctata* and *S. tenuis* on p. 13.)

Pterosagitta draco A. Costa

A small stout species with a voluminous collarette.

KEY TO SPECIES

Largely based on general appearance of preserved specimens.

This key includes only those planktonic species occurring or likely to occur in the European area.

Species rigid	1
Species flaccid	14
1. Very transparent	2
Not transparent	4
2. Tail about one-third total length, species very narrow and small	<i>K. subtilis</i>
Tail about one-quarter total length or less	3

3. Small but sturdy species, short ovaries, gut emerges from head as a thin white line	<i>S. setosa</i>
Large narrow and rather flaccid species with a very small rounded anterior fin	<i>S. hexaptera</i>
4. Species milky white	5
Species chalky white or yellowish	11
Species with red or orange gut	13
5. Vesiculæ seminales outstanding and horn-shaped, conspicuous even when immature	<i>S. serratodentata</i>
Vesiculæ seminales not obvious unless fully mature, when they are conical or wedge-shaped	6
6. Two pairs of lateral fins	7
One pair of lateral fins	10
7. Anterior fins do not extend forward as far as the ventral ganglion, vesiculæ seminales conical	<i>S. elegans</i>
Anterior fins extend forward to or close to the ventral ganglion, vesiculæ seminales widest at front	8
8. Collarette well marked and extends to anterior fin	<i>S. planctonis</i>
Collarette small	9
9. Vesiculæ seminales separated from posterior fin, close to tail	<i>S. bipunctata</i>
Vesiculæ seminales close to both tail and posterior fin	<i>S. friderici</i>
10. Collarette small, large species, oil globule usually present in gut	<i>E. hamata</i>
Collarette voluminous (but easily destroyed), small species	<i>P. draco</i>
11. Species short and stout, tail half the total length	<i>Spadella cephaloptera</i>
Species normal or thin in shape	12
12. Vesiculæ seminales outstanding, horn-shaped; head small	<i>S. serratodentata</i>
Vesiculæ seminales not outstanding, head very large	<i>S. macrocephala</i>
13. Two pairs of lateral fins, head longer than broad, normal neck	<i>S. macrocephala</i>
One pair of lateral fins, head broader than long, very narrow neck	<i>E. fowleri</i>
14. Species transparent	15
Species not transparent: specimens badly preserved or in poor condition on capture so that it is not safe to use a key based on appearance only	—
15. Lateral fins confluent	16
Lateral fins distinctly separated	17
16. Anterior fin extends forward to, or beyond the ventral ganglion	<i>S. maxima</i>
Anterior fin does not extend forward to the ganglion	<i>S. lyra</i>
17. Species long and thin	18
Species tumid	<i>S. enflata</i>
18. Anterior fins very small and well separated from ventral ganglion	<i>S. hexaptera</i>
Anterior fins extend forward to ganglion	<i>S. decipiens</i>

SHORT KEY TO SPECIES OCCURRING IN THE NORTH SEA AREA

Species transparent	1
Species milky	4
1. Species rigid	2
Species flaccid	3
2. Gut emerges from the head as a thin white line	<i>S. setosa</i>
Emergence of gut from head not obvious	<i>S. elegans</i> (juvenile)
3. Anterior fin extends forward to or beyond the ventral ganglion	<i>S. maxima</i>
Anterior fin does not extend forward as far as the ventral ganglion	<i>S. lyra</i>
4. Species short and stout, tail half body length	<i>S. cephaloptera</i>
Species thin or normal	5
5. Vesiculæ seminales outstanding and horn-shaped even when immature	<i>S. serratodentata</i>
Vesiculæ seminales not obvious unless fully mature	6
6. Two short pairs of lateral fins, anterior fin does not extend forward as far as ventral ganglion	<i>S. elegans</i>
One long pair of lateral fins beginning at ventral ganglion, usually an oil globule in the gut	<i>E. hamata</i>

NOTES ON THE IDENTITY OF *SAGITTA BIPUNCTATA*, Q. AND G. AND CLOSELY ALLIED SPECIES

It is now generally realised that since Quoy and Gaimard first described the species, the name *Sagitta bipunctata* has frequently been used, particularly in the earlier part of this century, to cover a range of Chætognatha belonging in reality to several species. Nevertheless, this error is being perpetuated by quotation from or reference to earlier work by more modern authors. For example: Hesse, Allec and Schmidt (1937, 1949 edition) on p. 166 state that "*S. bipunctata* has an unquestionable adaptability to brackish water," referring to an earlier paper by Ritter-Zahony. The brackish water form is now known to be *S. setosa*. On p. 236, the same authors, dealing with size variation, state "*S. bipunctata* reaches a length of 12 mm. in the Mediterranean and 44 mm. in the Arctic." Here the confusion is with *S. elegans arctica*.

In 1911 a Ritter-Zahony redefined *S. bipunctata* in more precise terms which ever since have become the accepted definition of this species.

This definition includes, amongst others, the following points:—

1. The anterior fin begins close behind the ventral ganglion.
2. The seminal vesicles are close to the tail fin and are separated by at least three-quarters of their length from the posterior fin.

The mature ovaries though given as 13 to 15% by Ritter-Zahony in 1910, *i.e.* relatively short, are in his 1911a paper given as elongated.

There appears to have been doubt about all these features in the minds of several authors, most of whom have quoted Ritter-Zahony's papers, and the following comments may help to clarify the issue.

It is unfortunate that Michael (1911) published a treatise on Chætognatha without having seen Ritter-Zahony's 1911 paper (although he quotes the earlier papers), and he figures *S. bipunctata* with anterior fins beginning considerably behind the ganglion and the seminal vesicles close to the posterior fin, though with short ovaries (10.5 to 20%). Another example of this kind of discrepancy is in the paper by Germain and Joubin (1916) who quote Ritter-Zahony's papers and figure "*S. bipunctata*" several times both by original drawings and copies from Fowler and Ritter-Zahony. In this work not a single one of the original drawings has the accepted features of *S. bipunctata*; all but one (their Plate IV, Fig. 4) as well as the photograph of the same specimen (their Plate VIII, Fig. 4), have the seminal vesicles close to the posterior fins and are probably *S. friderici* R.Z.

The specimen figured by Germain and Joubin as Plate IV, Fig. 4, is, I think, *S. decipiens* drawn from a shrunk specimen, so that only the posterior part of the anterior fin is seen, giving the impression of a short anterior fin well separated from the ganglion.

Ritter-Zahony described *S. friderici* from near the surface of the sea in the region of the Canary Isles, but was not at the time able to give any indication of the extent of its distribution and later Scaccini and Ghirardelli (1941a) found it in the same vicinity. Through the kindness of Mlle Faure of Casablanca and Dr. S. G. Gibbons from Capetown, I have been able to examine Chætognatha from both Morocco and South Africa. In both of these collections *S. friderici* was much more abundant than *S. bipunctata*, though both species were present. The former, therefore, seems to be much more widespread and numerous on the eastern side of the Atlantic than had been supposed, and this should be remembered when examining Chætognatha from this area. *S. friderici* is a neretic species whereas *S. bipunctata* is oceanic.

Further complications arise in regard to *S. tenuis* Conant, a species closely allied to *S. bipunctata* which Ritter-Zahony (1911a) included amongst *S. bipunctata*, but which Michael (1911) preferred to keep separate because of its very small size (5 to 6 mm.) at maturity and the difference in the anterior fins which begin close to the ganglion, (Michael did not consider that the fins in *S. bipunctata* were as close to the ganglion as in Ritter-Zahony's definition). Some specimens of *Sagitta*, which I was most pleased to receive, were sent to me for an opinion on their identification from North Carolina by Dr. W. H. Sutcliffe and from Florida by Professor Pierce. Both contained specimens which conformed closely to Michael's redescription of *S. tenuis*. Having seen the specimens, I agreed with Michael in keeping the species separate, and I am of the opinion that had Ritter-Zahony seen Michael's redescription, he also would have been inclined to accept the species as valid. Pierce (1951) has now examined the Carolina material as well as that from Florida and he also considers that *S. tenuis* must be retained as a valid species. He then says (p. 220) "On

the other hand *S. friderici* R.Z. is almost certainly a synonym of *S. tenuis*. The description and figures of *S. friderici* are in complete accord with the specimens from the west coast of Florida and Conant's *S. tenuis*. I have been privileged to examine specimens of both types, though neither has yet been found in the Scottish area, and I feel unable to accept this synonymy without reservation, though there is certainly a strong resemblance between the formulæ, and the eyes are also similar. *S. friderici* is much larger at maturity (10 to 13 mm.) than *S. tenuis* (5 to 8 mm.) and it has in general a greater armature though the figures given by Pierce now indicate an overlap that was not previously given in the literature.

There is evidence (Michael 1919) to show that differences in armature may be an environmental factor, though the tendency would appear to be that larger numbers of teeth are to be associated with higher temperatures and it is doubtful if the surface temperature at Cape Verd, where Ritter-Zahony found his *S. friderici*, would be much higher than at Florida. Germain and Joubin (1916) recognised *S. tenuis* as a valid species and confused *S. friderici* not with *S. tenuis* but with *S. bipunctata*. Owing to the marked size differences (Pierce's largest specimen is 8 mm.), and the somewhat different general appearance (Plate II, Figs. 12 and 13) it would seem advisable to retain the validity of both species at least until more work on their biology has been completed.

Tokioka (1939 and 1940), who quotes Ritter-Zahony as the authority used for identification, describes or figures *S. bipunctata* with long ovaries and an epidermal thickening between the posterior fin and the seminal vesicles but without commenting on these two points of difference. Thomson (1947), whose *S. bipunctata* with the epidermal thickening is certainly the same species as Tokioka describes, also quotes Ritter-Zahony's paper, but Thomson refers to this epidermal thickening as not having been mentioned in descriptions from Atlantic waters. He is replied to by Fraser (1949b) who maintained that the Atlantic specimens he has seen had no such thickening. Since then, however, in one of the collections sent by Mlle Faure from Morocco there was a single specimen which was obviously Tokioka's type with the epidermal thickening between the posterior fin and seminal vesicles. Its long ovaries, armature, corona and strongly evident tactile sensory organs all fitted Tokioka's description. Mlle Faure has since found sixty or more specimens and has measured the percentage length of the ovaries of these and of about 250 specimens of the normal *S. bipunctata*. She finds them to be in one continuous series, though they are never quite so long as Tokioka gives. It would therefore appear that the length of ovary in *S. bipunctata* can exceed the 20% given by Ritter-Zahony, (perhaps less often in the Atlantic forms than in the Pacific forms), and that an epidermal thickening between the seminal vesicles and posterior fin is normally found associated with full maturity.

The question of the length of the anterior fin of *S. bipunctata* seems still a little uncertain. Ritter-Zahony (1911a) gives the following description "Vorderflossen knapp hinter dem Bauchganglion beginnend" but in his Tierreich (1911b), he says "Vorderflossen dicht hinter dem Bauchganglion beginnend." Michael gives a space of 4 to 10%, usually 7%, of the body length between the two. Burfield and Harvey (1926) figure a distinct space of about 2½%. It would thus appear that "knapp" should not be interpreted too strictly and that there is probably a good deal of variation in the actual position of the beginning of the fin, but that it is nevertheless sufficiently close to the ventral ganglion to enable it to be used as a character separating *S. bipunctata* from *S. elegans* and *S. setosa*. Mlle Faure states that in *S. bipunctata* the fin begins slightly behind the ganglion, whereas in *S. friderici* it begins actually at the ganglion. I have not personally seen sufficient specimens of *S. bipunctata* to be able to assess the degree of variation, but I have found considerable variation in this feature in *S. maxima* where the anterior fin may begin from half way up the ganglion to some 10% in front of it. It is also true that it is extremely difficult to ascertain with precision the exact beginning of these delicate fins even in good specimens. In badly preserved material it is almost impossible. Ghirardelli (1950, p. 15) has found similar specimens in the Mediterranean and discusses the probable synonymy of this form of *S. bipunctata* with *S. californica* Michael.

Since writing the section on the validity of *S. bipunctata* Mlle M. L. Faure, with whom I have been in correspondence, has published the details of her findings concerning *S. friderici* and *S. bipunctata* from the Morocco area: 'Contribution à l'étude morphologique de deux chétognathes des eaux atlantiques du Maroc: *Sagitta friderici* Ritter-Zahony et *Sagitta bipunctata* Quoy et Gaimard'. *Vie et Milieu, Bull. du Lab. Arago, Paris*, Tome III. fasc. 1, 1952. Her findings confirm and amplify the brief statements given here.

CORRELATION OF OCCURRENCE WITH PHYSICAL CONDITIONS

It is possible, from a study of the distribution of indicator species over a period of years, to arrange such organisms in ecological groups without defining the habitats in chemical or physical terms. In this paper, for example "indigenous North Sea water," "oceanic" and "coastal" water are such habitats. Russell (1935a) discussed "western" and "south-western" water in a similar way and later (1939) he described several ecological regions round the British Isles. For most "indicator" purposes such a general nomenclature is all that is necessary, especially when the indicators are used to separate water masses which have as yet imperfectly known chemical or physical differences, which appear to be very small. To define the strict limits of tolerance of any one species, or group of species, would involve much physiological research beyond the policy at Aberdeen; nevertheless some information can be extracted from observations at sea and correlations made between the distributions of various organisms and the conditions in which they are found.

In dealing with distributions of Chætognatha, many authors have discussed the depth, and to a less degree, temperature and other factors. Furnestin (1938) correlated the distribution of three species of *Sagitta* in the North Sea and adjacent areas with salinity and found that *S. setosa* was associated with salinities of less than 35‰, *S. elegans* with salinities of greater than 35‰ and *S. serratodentata* with salinities of over 35.4‰.

The year 1949 was chosen from the Scottish series of Chætognatha collections to make some such analyses, as that was the year when most records were available with approximate depths of capture which could be correlated with the observed hydrographic data. Correlations have been made for temperature, salinity and depth and are based on the percentage occurrence (presence or absence) in the different categories with little allowance for numerical abundance at each occurrence.

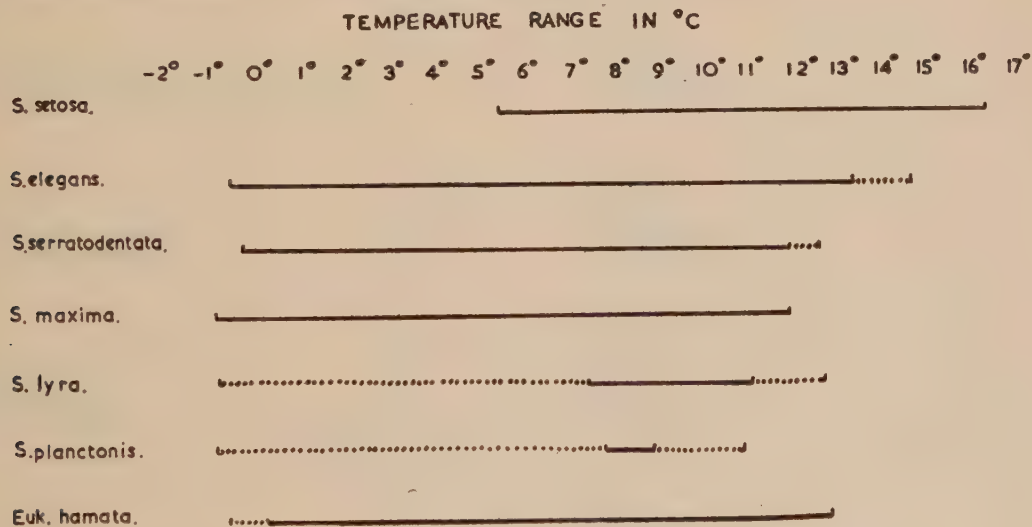


FIG. 2

The temperature range of seven species of Chætognatha taken in the Scottish area in 1949. Where the the numbers of individuals taken is recorded as greater than "few" a continuous line is shown; where numbers are recorded as "rare" or "very rare" the line is dotted.

Temperature ranges for seven species taken in 1949 have been plotted in Text Figure 2. At sea, temperatures are themselves linked with depth and other factors and the observations are subject to the natural limits of the area investigated. Although Figure 2 shows the preference of the various species it only does so within these sampling limitations, *e.g.* the lower limit of range of *S. maxima* is given as -0.8°C . which is the lowest observed temperature at which net hauls were taken. *S. setosa* is shown to have a higher temperature range than *S. lyra* because solar radiation warmed the surface of the North Sea where *S. setosa* commonly exists, but *S. lyra* was only caught outside its natural habitat in places where the warm current conveying it had already become cooled.

The salinity correlations, Text Figure 3, probably give more valuable information than the temperature correlations. If the percentage occurrence as actually sampled is graphed against the salinity the resulting figure would be misleading because the largest number of samples were taken in the salinity range 34.75 to 35.25‰, and figures above or below this range would be therefore proportionally underweighted. The number of observations at different salinity ranges have therefore been taken into account in producing the graphs. These figures clearly illustrate the low salinity distribution of *S. setosa*, which extends from about 35‰ to at least as low as 29‰, the limit of Scottish sampling in 1949. Figures above 35‰ are represented and these are probably due to capture of a few *S. setosa* in non-closing nets from lower salinity surface water overlying deeper layers of higher salinity. *S. elegans* is chiefly associated with water of about 35‰ and its extension into lower salinity waters is much less than with *S. setosa*.

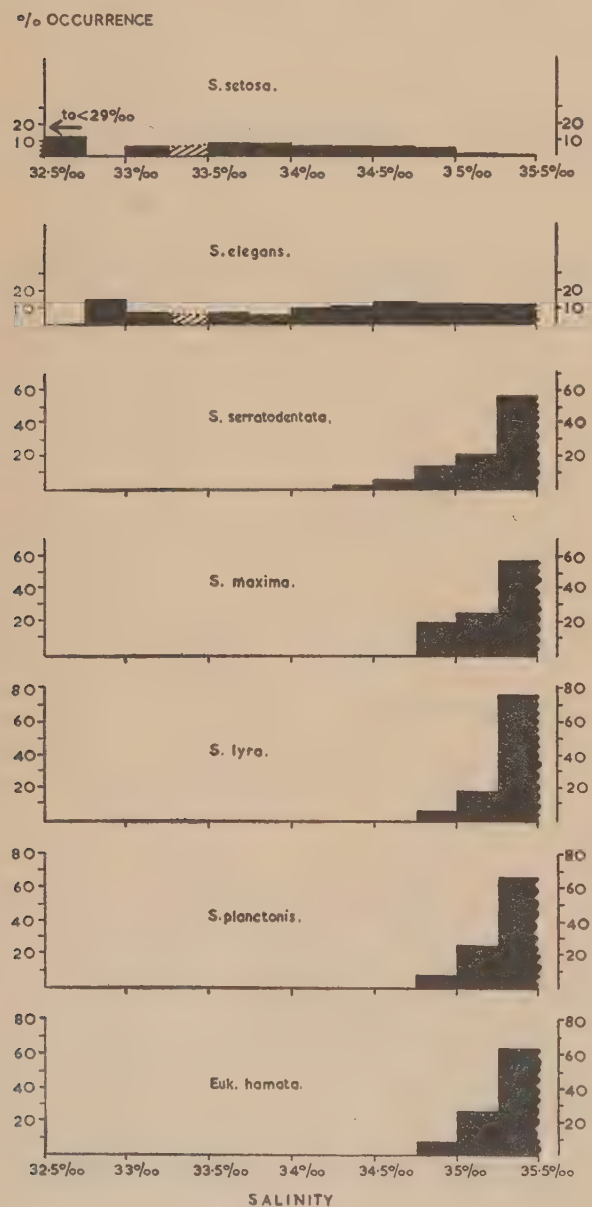


FIG. 3

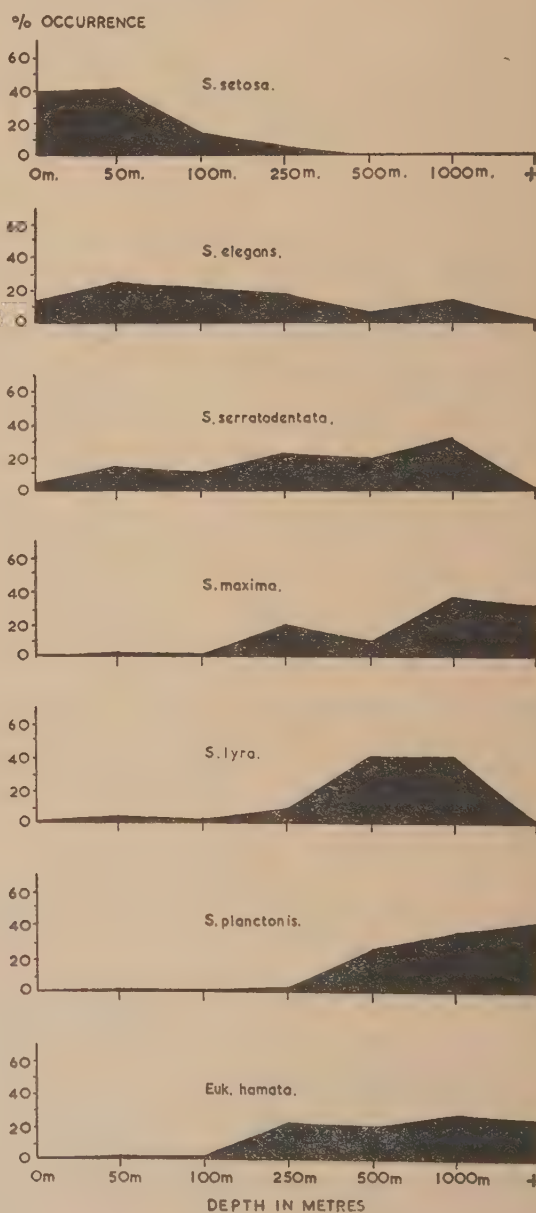


FIG. 4

The salinity and depth ranges of seven species of Chætoagnathy taken in the Scottish area in 1949; (for details of construction see text).

The other species have even less tolerance for salinities lower than 35‰, and are mostly associated with salinity higher than 35.25‰. The species are less and less tolerant in the following order, *S. serratodentata*, *Eukrohnia hamata*, *S. maxima*, *S. planctonis* and *S. lyra*.

The depth correlations (Text Figure 4), like those for salinity, have been corrected to allow for uneven numbers of sampling observations. Nevertheless, the graphs require a further correction because the nets, being non-closing, would all sample the upper layers to a small extent as well as at the specified depths. The amount of correction to apply for this factor is dependent upon the proportion of the number of the particular species found in the upper layers compared with lower regions. For example, a surface living species is more likely to be caught when hauling a net from deep water through surface layers than is a bottom species living out of its usual habitat. Thus in *S. setosa* the points below 100 metres are probably surface records. The graphs for *S. elegans* and *S. serratodentata* should show a somewhat greater representation near the surface and less in deep water, but *S. maxima*, *S. planctonis* and *Eukrohnia hamata* would need only slight correction in this direction. It must be borne in mind that these graphs, like those for temperature and salinity, are also subject to sampling limitations, particularly because depth in the sea is usually associated with temperature. Thus the falling off in the graph of *S. lyra* at depths greater than a 1,000 m., though a true picture of the conditions off the Scottish coast, may be largely due to the lower temperature at these depths and not due solely to the depth factor. The difference between a really deep water species like *S. planctonis* and a moderately deep water species like *Eukrohnia hamata* is clearly shown. The figures for *S. elegans* and *S. serratodentata* both show a deeper aspect than might be expected even after a correction is applied to allow for the non-closing of the nets. This is probably due to using presence or absence as an assessment for the percentage occurrence whereas in reality, though they are frequently sampled at deeper levels, their numbers at these levels are small compared with those sampled in the upper layers. The method of sampling is not suitable for discussing the effect of diurnal vertical migration on these figures, but it is known that although Chætognaths do migrate in this way their range is not very great. Moore (1949) gives 105 metres range for *S. hexaptera* and *S. bipunctata* but the other species he has studied have ranges of less than 100 m. Farran (1947) studying *S. elegans* showed the range to be under 75 m. in young specimens and about 100 m. in specimens larger than 15 mm. As it may be assumed that there were approximately equal numbers of night and day hauls used to produce the Text Figure 4 the results may be assumed to represent an average value. When considering the value of the Chætognatha as indicators of upwelling of deep water, the effect of diurnal migration should not be overlooked though it is not likely to be of great significance.

Having correlated the various Chætognatha species with different types of environment and bearing in mind that the water in which they live is constantly being carried from one place to another, both vertically and horizontally, we can then use the later stages of distribution to give some indication of the local hydrographical conditions and of the origin of the water masses concerned. These indications are of two types: first, the tracing of the actual movements of the water, and second, the elucidation of physical and chemical conditions or the distinction between the different water masses in a given locality. Only the first of these is dealt with in this paper, the second being referred to in passing (p. 46). A study of Chætognatha alone cannot provide all the necessary evidence and confirmation from other groups of plankton organisms is always desirable. In this connection a brief list of associated species is given:

With *S. setosa*:—

the medusæ *Aglantha rosea* and *Eutonina indicans*
the copepods *Isias*, *Corycæus* and *Labidocera*

With *S. elegans elegans*:—

rich crustaceous plankton including *Calanus finmarchicus*, *Candacia*, *Metridia lucens*, *Nyctiphanes couchii*, *Thysanæssa inermis* and many decapod larvæ, such as *Munida*.

With *S. serratodentata*:—

Rhincalanus, *Eucalanus*, *Meganyctiphanes*, *Thysanæssa longicaudata*, *Pelagia perla*, *Cosmetira*, *Aglantha digitalis*, *Tomopteris*, *doliolids*, *Clione*, *Agalma* and *Physophora*,

With *Eukrohnia hamata*, *S. maxima* and *S. elegans arctica*:—

Calanus hyperboreus, *Euchæta norvegica*, *Pleuromamma robusta*, *Metridia longa*, *Meganocytiphanes*, *Oikopleura vanhoeffeni*, *Limacina helicina*, *Sergestes arcticus*, *Laodicea*, *Physophora*, *Dimophyes* and *Scopelid* fish, particularly *Myctophum glaciale*.

With *S. lyra*:—

Clio pyramidata, *Diacria*, salps, doliolids; siphonophores such as *Hippopodius*, *Chelophyes* and *Agalma*; *Cosmetira*, *Limacina helioides*; various cephalopods such as *Tracheloteuthis* and *Taonidium*; *Stylocheiron*, *Euchirella rostrata*, leptocephali and *Fierasfer* larvæ.

With *S. planctonis*, *S. macrocephala*, *Euk. fowleri* and *K. subtilis*:—Siphonophores such as *Vogtia*, *Praya* and *Rosacea*; *Travisiopsis*; bathypelagic copepods such as *Euchirella spp.*, *Gætanus*, *Gaidius*, *Scottocalanus*, *Lophothrix*; deep sea fish such as *Argyropelecus*, *Cyclothone*, *Lampanyctus*, etc.

Some of these names are repeated under two Chætognath headings because their distribution overlaps the Chætognath distribution.

One must remember of course that the area of origin of certain species of *Sagitta* is by no means a small one and indeed could be very wide and, secondly, that the plankton population of a given body of water usually varies enormously from season to season and from year to year. It must be emphasised that the indications of water movements given by a study of plankton in general and Chætognatha in particular are *indications* only, although sometimes the evidence can be very strong indeed. The presence of genuine deep water species in upper waters would mean that the water had been upwelled from a deeper zone, and the condition of the individuals would give some indication of how recently this had taken place. To know immediately that water now of a certain (perhaps cold) temperature had recently been raised from a deeper layer, or that its present temperature had been reached by mixing two bodies of water together from separate warm and cold streams, is of real value.

To deal first with the use of indicator species as an aid in tracing movements, the distribution of Chætognatha and other species over a series of years has been examined.

THE YEARS 1936-39 AND 1946-50

Brief statements on the hydrographical conditions in the area investigated by Scottish research vessels during the years 1936-39 and 1946-50 are given, followed by correlated descriptions of the distribution of some of the indicator species, with particular emphasis on the Chætognatha.

The plankton information is based on samples taken by horizontally towed non-closing nets 1 m. in diameter. The mesh used from 1936 to 1939 was the pre-war cheese cloth of about 20 meshes per inch. During 1946 and 1947 stramin of about 13 meshes per inch was used but this has since been replaced by silk with about 26 meshes per inch. The nets were towed at approximately 2 knots for a quarter of an hour at the surface, 50 m. (20 m. in 1950), and 100 m. (or near the bottom) over most of the relatively shallow area, but in depths greater than 300 m. the bottom net was towed at 250 m. In 1949 and 1950 1 m. nets were also used obliquely in hauls from 250 m. or 100 m., and in very deep water from as deep as the available warp permitted, so that the net would fish an oblique column from depths of approximately 1,000 m. depth to the surface. The collections are not regarded as quantitatively accurate, for plankton indicator work presence or absence of a particular organism is usually sufficient for the requirements, whilst differences of such magnitude as rare and abundant are of value. The condition of the animals on capture—whether the population is thriving or dying—can be more important than actual numbers. Little allowance is therefore required for differences in the material used to make the nets, filtration efficiency or other variable factors.

The charts for the different years are annotated so as to show the month as well as the position in which the samples were taken, whether or not they contained the organisms concerned. The station position is indicated by a letter according to the month of the year and the letters used are the same throughout the charts. They are: Z=January, F=February, R=March, P=April, M=May, J=June, Y=July, A=August, S=September, O=October, N=November and D=December. For the year 1939 the data from the 1 m. nets have been supplemented in June by information from a 2 m. net hauled vertically and in such positions the symbol "j" is used instead of "J".

The symbols used for the Chætognatha are indicated on the charts and are identical throughout. They indicate presence or absence only except for *S. elegans* in which occurrences recorded as rare have been ignored. This has been done because *S. elegans* is so widely distributed in small numbers in areas of overlap, etc., that to chart the presence of small numbers equally with larger would confuse the issue. It has not been thought practicable to chart an assessment of numerical abundance of the various species, as

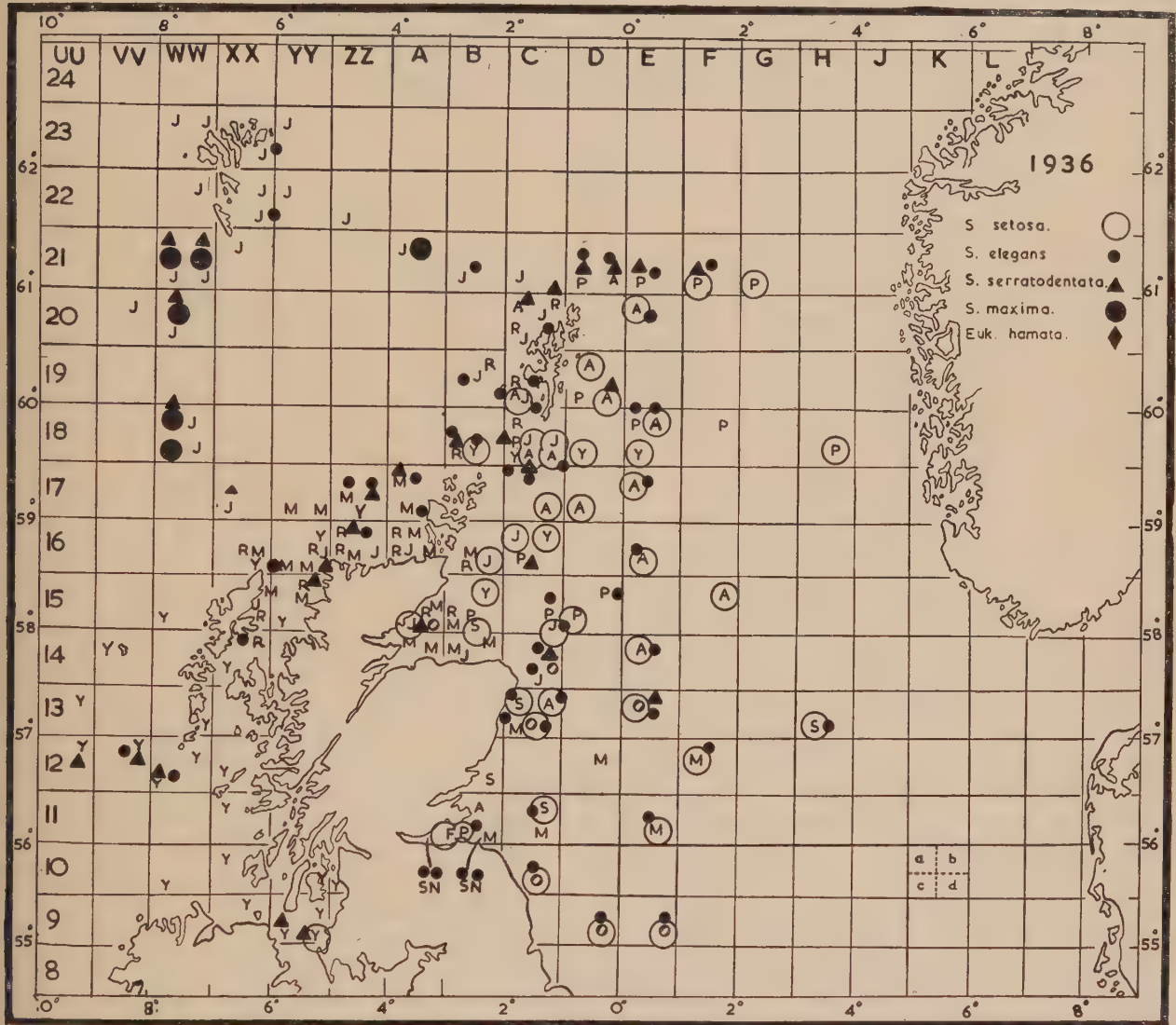


CHART I

The distribution of Chætognatha in 1936

F=February, R=March, P=April, M=May, J=June, Y=July, A=August, S=September, O=October, N=November. For further explanation of charts see text.

to do so would make the charts unnecessarily complicated. For charts other than those of Chætognatha the symbols are explained on the particular charts, but the letters indicating the station position are those used also for the Chætognatha.

The position of the stations is recorded to the nearest sub-square. Each square represents an area bounded by 1° of longitude, designated by a letter A, B, C, D, etc., and $\frac{1}{2}^\circ$ of latitude designated by a number 12, 13, 14, etc.; each is divided into four sub-squares, a, b, c, d, as indicated on chart I. The open ring symbol for *S. setosa* has been placed round the station position letter and the other symbols placed conveniently near by. It is of course the station letter that indicates the place of capture and not the position of the specific symbol.

1936, Chart 1

The year 1936 appears to have been a year of less Atlantic influx into the northern North Sea in the spring than was usual in the years immediately preceding and following, though it increased in the summer. Eggvin (1937) states that 1936 was a poorer year of influx than 1935, with lower bottom temperatures in spring. Smed (1949 a and b) shows that although the spring surface temperatures in his area "J" (Faroe-Shetland) had a positive anomaly and his areas "K" (Scottish North Coast) and "F" (North-Western North Sea) had negative and then positive anomalies in 1936, these anomalies were very slight compared with the general high trend since 1932, and compared with the positive anomalies from the same areas in summer and autumn. The rise in area "K" was later than in "J" and "F". The Fishery Board for Scotland report for 1936 is very similar in its statement (p. 53) and says that there was less Atlantic water on the Wyville Thomson Ridge in June than on the same section a year earlier.

The distribution of *Sagitta* taken in Scottish plankton collections in 1936 has already been described (Fraser 1937) and can be correlated with the hydrographical background. *S. serratodentata*, indicating Atlantic water, was found in April on the line 61°N east from Flugga to just beyond 1°E. It was not found to the immediate east of Shetland (D19c and E18a) although it was present nearer Fair Isle (C18c) and east of Pentland (C16c) at that time, having also been found north of Shetland and north of Orkney in March. It was absent in the North Sea generally. Summer collections on the Faroe-Hebrides line and off the west Scottish coast also contained *S. serratodentata* although it was not taken on the Faroe-Shetland line or near the Faroe Isles. By August its distribution on the 61°N line east of Flugga was apparently restricted to west of 0° as it was not found in E20a. It had however reached the Fraserburgh grounds and the Gut by October.

The weak influx of oceanic water into the North Sea in 1936 probably explains the distribution of *S. setosa* which, in 1936, was unusually far north but to the east of the small region of influx shown by *S. serratodentata*. For example, the April collections of *S. setosa* were east of 1°E and therefore east of the area of distribution of *S. serratodentata*, and in August *S. setosa* was found immediately east of 0° in E20a but not west of 0° in D21d where *S. serratodentata* was taken. There appeared also to be distinct evidence of a movement through the Fair Isle-Sumburgh passage from east to west, carrying with it *S. setosa* to the south-west coastal waters of Shetland in June and August, a movement illustrated by Tait (1934 and 1937) in his charts of surface drift currents in the northern North Sea and Faroe-Shetland Channel. *S. setosa* is known to be indigenous in the Irish Sea (Pierce 1941, Pierce and Orton 1939) and the presence of this species off the south-west Scottish coast (YY9d) indicates an outflow of Irish Sea water through the North Channel. This process was noted in 1934 by Russell (1935a) who identified *S. setosa* from the coasts of Northern Ireland and attributed their origin to the Irish Sea. Such an outflow is shown in this paper to have occurred also in 1949 and 1950.

S. maxima from cold deep water was found on the Faroe-Butt of Lewis line only north of the edge of the Continental Shelf but the observations from this area in 1936 were confined to June.

The distribution of *S. elegans* indicating areas of mixed Atlantic and coastal water are shown on chart 1 and require no special comment. No other Chætonognatha were found in 1936.

Fraser (1949) states that the Atlantic plankton off Shetland in August did not penetrate into the North Sea although a few doliolids of unknown origin were, like *S. serratodentata*, found in September and October off the east coast of Scotland.

1937, Chart 2

According to the Fishery Board for Scotland report the year 1937 was characterised hydrographically by a poor Atlantic influx in spring which only reached its maximum in August and thereafter rapidly declined. The actual inflow appears to have been weaker than for the previous five years, although the salinity was still above the average. The graphs and figures given by Smed (1949a and b) for surface temperature anomalies in his areas "J", "K" and "F" confirm the Scottish hydrographical results by showing a marked drop in March and reaching a positive maximum in August, thereafter dropping sharply in September, to be followed by a further rise in October and a fall in November and December. The Fishery Board for Scotland report states that "during 1937 there was direct evidence of three distinct-

tive types of water in the northern area—Atlantic water, northern or Boreal water and continental water from the Baltic region principally. The presence of these three types is reflected in the plankton hauls for the year.” The Scottish plankton results (*ibid.* and Fraser 1949), show that although the influx of oceanic species into the area in 1937 was greater than in 1936, there was also a greater arctic influence. The presence of *Velella* in fair abundance off Barra in July (Forrest 1938) suggest the presence of warm oceanic water off the Scottish west coast.

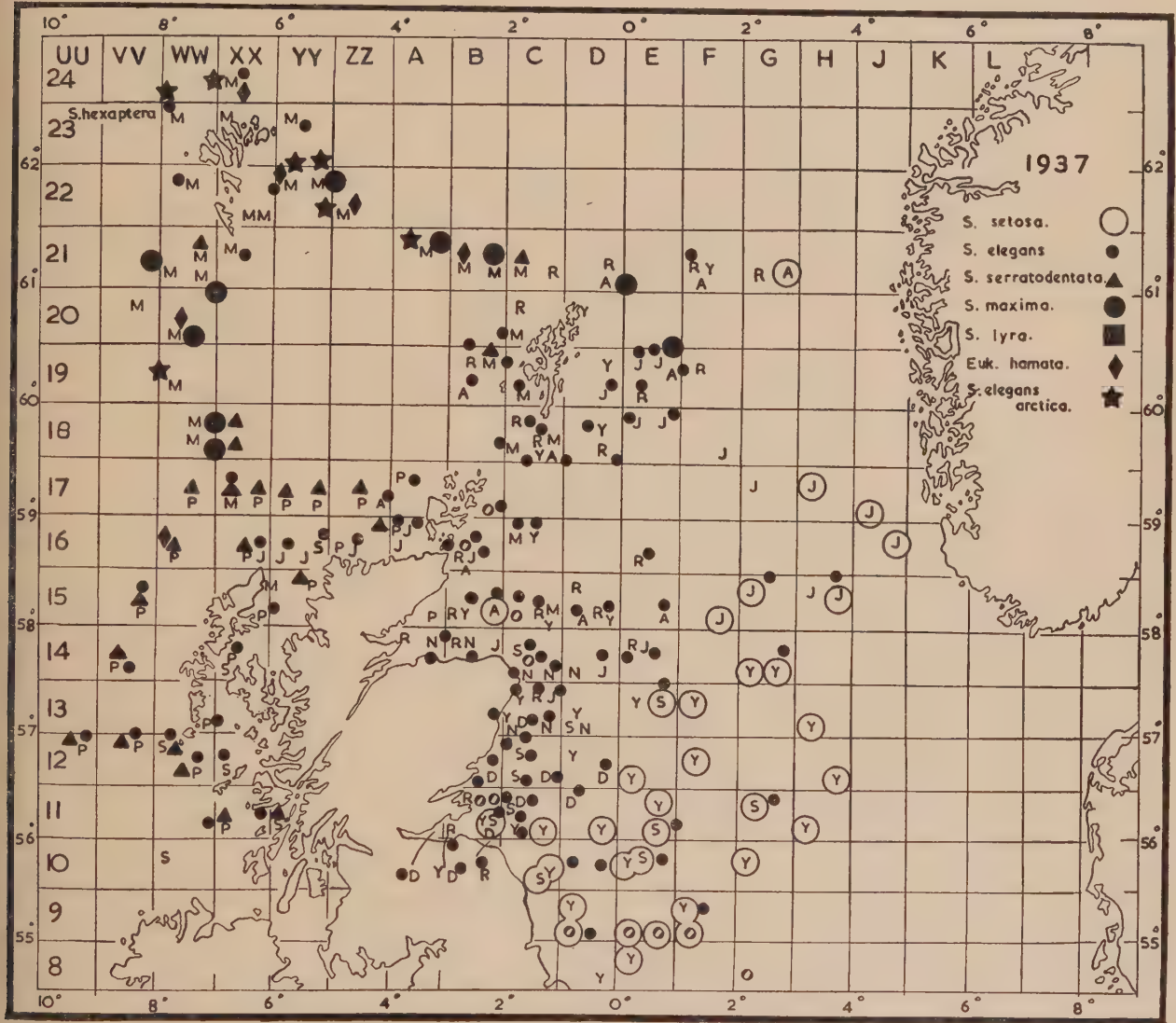


CHART 2

The distribution of *Chatognatha* in 1937

R=March, P=April, M=May, J=June, Y=July, A=August, S=September, O=October, N=November, D=December.

The distribution of *Sagitta* from Scottish plankton collections of 1937 have already been discussed in relation to the hydrological significance (Fraser 1939) and are therefore only briefly referred to here.

S. setosa was more or less confined to the central North Sea south and east of a line from the Scottish border towards the Norwegian Deep, *i.e.* nearer to Russell's (1935a) figure 6 than in 1936 but curving northwards to the 61°N parallel at about 2°E thus illustrating the influence of the low salinity surface effluent from the Baltic region.

S. serratodentata was abundant in collections off the west Scottish coast in April and south of the Wyville Thomson Ridge in May. There was evidence that it reached west of Shetland in May, but in contrast to 1936 and many following years, it was poorly represented in the northern North Sea not only in spring

but throughout the rest of the year. *S. maxima* on the other hand was present north of the edge of the Continental Shelf in May and shows clearly the relationship of the plankton in that area with that on the Faroe-Shetland line in May and its penetration into the northern North Sea by the north and east of Shetland in August.

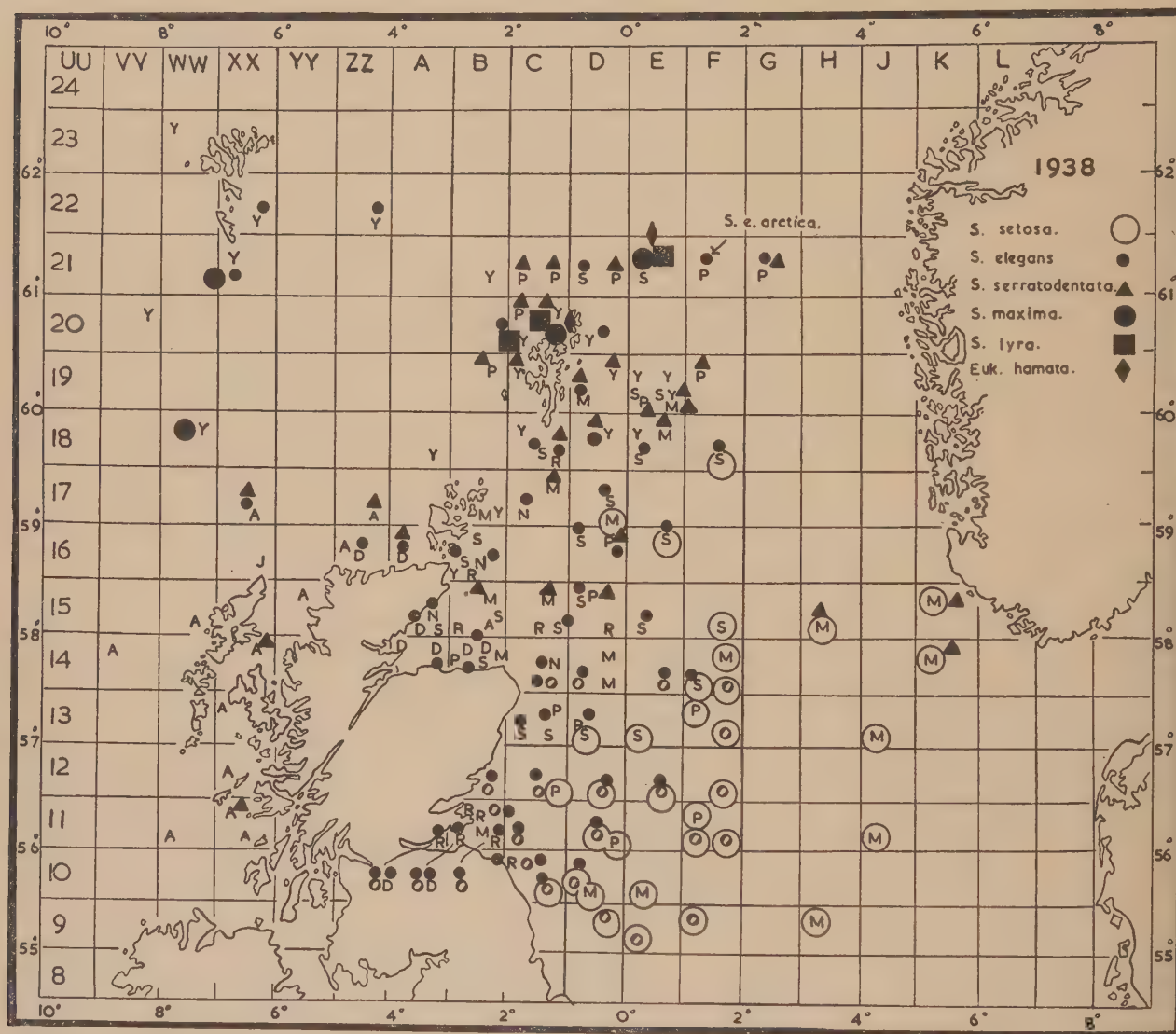


CHART 3

The distribution of Chæto gnatha in 1938

R=March, P=April, M=May, J=June, Y=July, A=August, S=September, O=October, N=November, D=December.

Eukrohnia hamata had a distribution similar to, but rather wider than *S. maxima* in the Faroe and Butt of Lewis areas but it was not taken east of Shetland. A few *S. hexaptera* were taken north-east of Faroe in May.

S. elegans clearly illustrated its stated associations with mixed coastal and oceanic waters, being almost absent in "pure" oceanic waters and abundant in inshore waters off the west coast, on the Faroe Plateau, off Shetland and in the north-western North Sea where it was particularly abundant off the east Scottish coast from July to December.

This abundance of *S. elegans* in the north-western North Sea, in contrast to 1936 when *S. setosa* was distributed more northerly than usual, would indicate, contrary to the hydrographical views expressed, that the 1937 influx was stronger than 1936. Smed's figures are for temperatures only and the hydro-

graphical deductions given in the Fishery Board for Scotland are based in part on temperature readings. It might therefore be that the volume of oceanic water was actually greater than in 1937, but because of the greater arctic influence the temperatures were less than might be expected and the significance of the Fishery Board's statement that the salinities were still above the average might be explained.

S. elegans arctica was found on the Faroe Plateau and in the Faroe Channel, almost invariably occurring each time, and only when, the temperature at 100 m. was below 8°C. (Fraser 1939).

1938, Chart 3

According to the Report of the Fishery Board for Scotland for 1938 the returns for drift bottle liberations indicated a strong pulsation of Atlantic water in the northern North Sea early in the year. The intensity fell away during April and May so that the middle North Sea temperatures north of Peterhead were slightly below normal. A renewed thrust southward occurred in June which was reduced in August and renewed again in September only to fall off once more. In March drift bottles from east Scottish liberations were later recovered from Denmark, Sweden and Norway. There was little evidence of Baltic outflow. Lucas (1941) showed that many diatom species were carried away from the Scottish coast eastwards and southwards in the autumn of 1938. Smed's surface temperature anomalies were strongly positive in March but at a minimum in July rising again in August to a new high figure, *i.e.* a month earlier than suggested from the Scottish data.

This general hydrographical statement is supported by the Chætoognath distribution. For example, *S. serratodentata* was brought into the area with the early influx and was found in March, April and May in the area around Shetland, Fair Isle and in the Gut. In 1937, when the Baltic effluent was marked *S. setosa* was found in the 61°N line east of 1°E but *S. setosa* was not found there in 1938 thus supporting the suggestion of a small Baltic outflow. A further biological support for the inferences from drift bottles stranded on the Danish coast is the presence of *S. serratodentata* there in May.

Not many plankton samples were taken from the Faroe Channel in 1938 but these showed a general paucity of oceanic species of Sagitta there in July (Smed's period of minimum temperature anomaly) though, as in 1936 and 1937, *S. maxima* was found north of the edge of the Continental Shelf in July. Oceanic species of Sagitta (*S. maxima*, *S. serratodentata*, *S. lyra* and *Eukrohnia hamata*) were found to the north and west of Shetland having presumably arrived there before this period of paucity. Of these only *S. serratodentata* penetrated into the North Sea. Marshall (1948) illustrates the transportation of Clione into the east Shetland and east Orkney areas from July onwards with a maximum in October. Clione is, of course, more tolerant to changes in conditions than *S. lyra* or *S. maxima* and this combination would indicate that by July the influx reported by the Fishery Board for Scotland was already reduced and had risen again in August as suggested by Smed's figures, *i.e.* somewhat earlier than Fishery Board for Scotland estimates. Although in the later months of the year there were no strictly oceanic species of Sagitta taken in the northern North Sea, the evidence of increased influx is illustrated by the extended distribution of *S. elegans* along the east Scottish coast to the exclusion of *S. setosa* in the areas off the Tay at least in October, and off the Firth of Forth in October and December. This is also illustrated by Marshall (1948) from Continuous Plankton Records, and by Fraser (1949a) who cited an incursion of salps and doliolids via north of Shetland in September, although this incursion was not a large one, nevertheless the surviving old nurse stages of the doliolids were distributed in the north-western North Sea in September, October and November and even penetrated into the Firth of Forth.

1939, Charts 4 and 5

Owing to war conditions intervening the 1939 records are incomplete, but there is nevertheless sufficient information to make a short hydro-biological correlation. The brief summary given by Clark (1947) for the 1939 hydrographic conditions states that "the first observations for the year, in March, in the north-western area of the North Sea, showed the normal spring oceanic influx to be about its climax, although not apparently of abnormal intensity since it clearly waned during April until, in May, subnormal conditions were obtained in the middle North Sea area. The return to normal conditions was evident by July and a month later it was obvious that the oceanic incursion from the north was approaching a

second maximum for the year, when temperatures and salinities were appreciably above average over almost the entire northern North Sea." He also states that "plankton distributions in the northern and middle North Sea followed generally the disposition of the several water masses." Smed's surface anomaly figures for his areas "J", "K" and "F" indicate however that the second maximum did not begin until August and reached a maximum in September. Tåning (1943, pp. 73 and 76) says that an outstanding characteristic for the year as against all recent years (probably in this century) was the colossal influx of

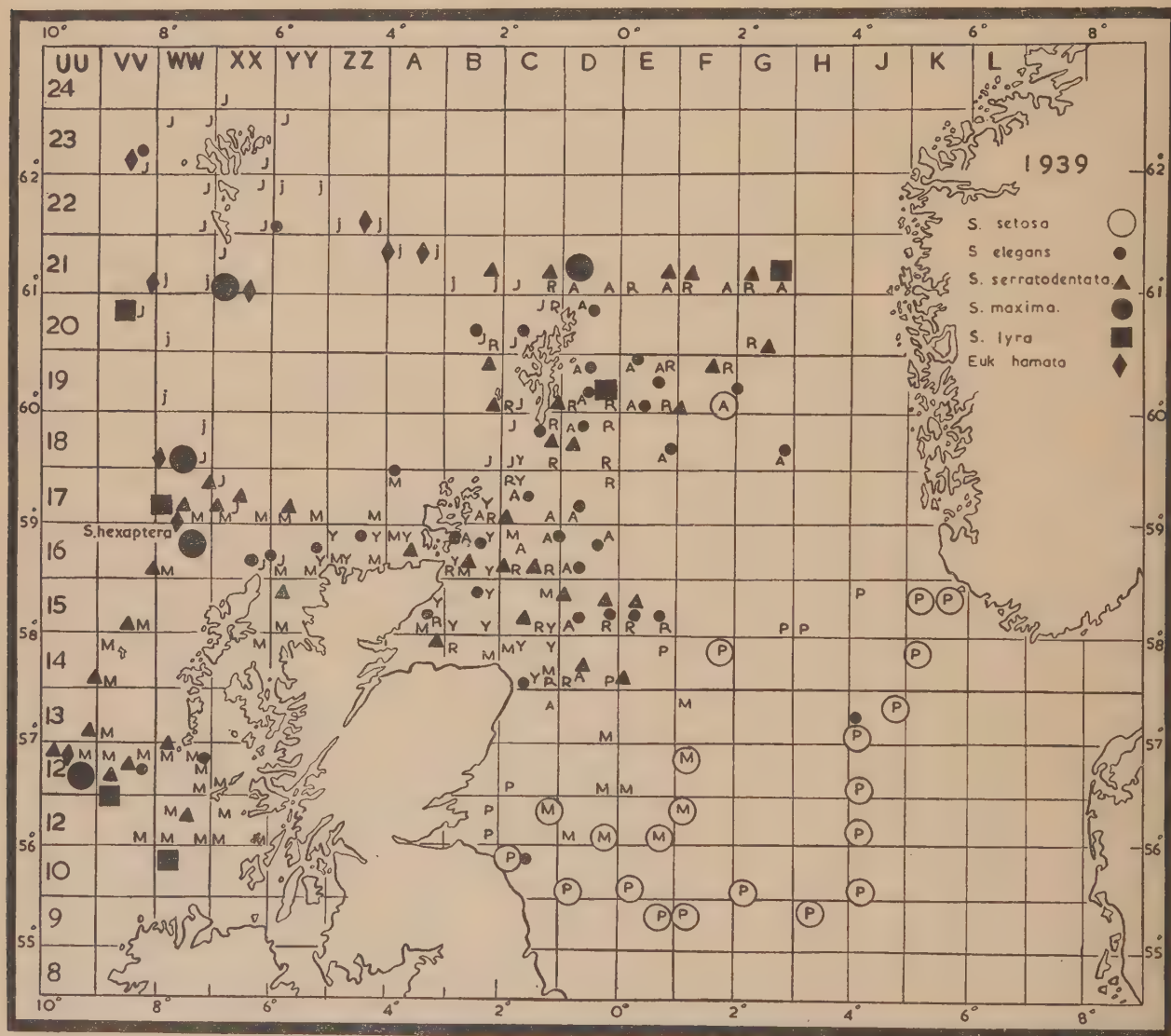


CHART 4

The distribution of Chætognatha in 1939

R=March, P=April, M=May, J=June, Y=July, A=August, j=2 metre vertical nets in June.

warm Atlantic water into the Iceland area. Sund (1943) reports from Scottish results that the spring influx to the north-eastern area was decidedly weaker than in July. Clark (1947) suggests a southerly extension of sub-arctic water damming back the warmer oceanic water.

The early spring maximum influx is reflected by the Scottish Chætognatha. *S. serratodentata* was widely distributed around and to the east of Shetland, Fair Isle and Moray Firth areas and in the Moray Firth. In the absence of March sampling west of Orkney, the route of the Moray Firth specimens is uncertain, but in view of other years it seems likely that the early influx was both via north of Shetland and north of Orkney. This view is supported by the distribution of *Laodicea* and *Cosmetira* later in the year (see below).

S. elegans was present in abundance throughout the summer from the Butt of Lewis along the north coast to Orkney, Shetland, Moray Firth and Fladen, but was absent or only very scarce in April/May south of 57°N in the North Sea and in the "pure" oceanic waters of the Faroe Channel and of the west Scottish coast. *S. setosa* dominated south of 57°N and was not found in the Moray Firth or Shetland area except for a single record in August 90 miles east of Shetland. The distribution of *Sagitta* in the North Sea shown by Marshall (1948, Plate XCI) confirms the Scottish findings.

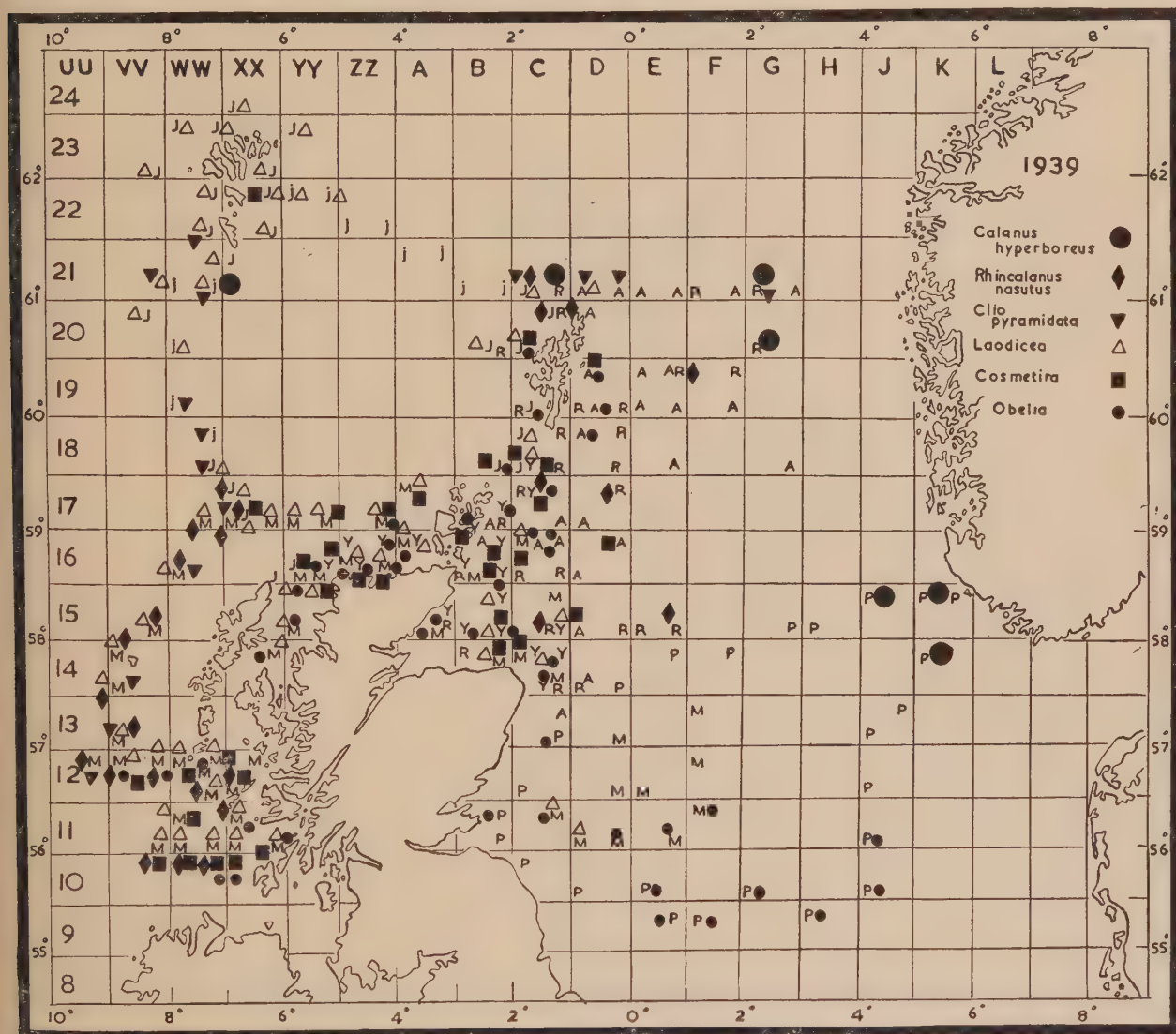


CHART 5

The distribution of other indicator species in 1939

R=March, P=April, M=May, J=June, Y=July, A=August, j=2 metre vertical nets in June.

The May oceanic samples off the west coast contained *S. serratodentata*, *S. lyra* and *S. maxima* which were carried into the Faroe Channel south of the Wyville Thomson Ridge in June, only reaching the 61°N line east of Shetland in August where there was evidence of penetration into the North Sea east of 2°E (*S. lyra*). The arctic influence is shown by the dominance of *Eukrohnia hamata* on the southern end of the Faroe-Butt of Lewis line and on most of the Faroe-Shetland line, though it was also present (with *S. maxima*) in small numbers in areas of upwelling of deep water to the west and north of the Continental Shelf.

In addition to the Chætogonatha, other plankton species can be used to illustrate the application of the indicator principle in 1939. The effect of the arctic water on the 61°N line is illustrated by the presence of

Calanus hyperboreus there in March. Doliolids were very abundant in the western entrance to the Faroe Channel in May and June (Fraser 1949a) and although they had not reached the east side of Shetland in any numbers when sampling ceased in August, Tåning (1943) shows that they were present on the Shetland side of the Faroe-Shetland line in the middle of July. Lucas, Marshall and Rees (1942) show that on the Continuous Plankton Recorder line from Sule Skerry towards Iceland, cold water forms such as *Metridia*

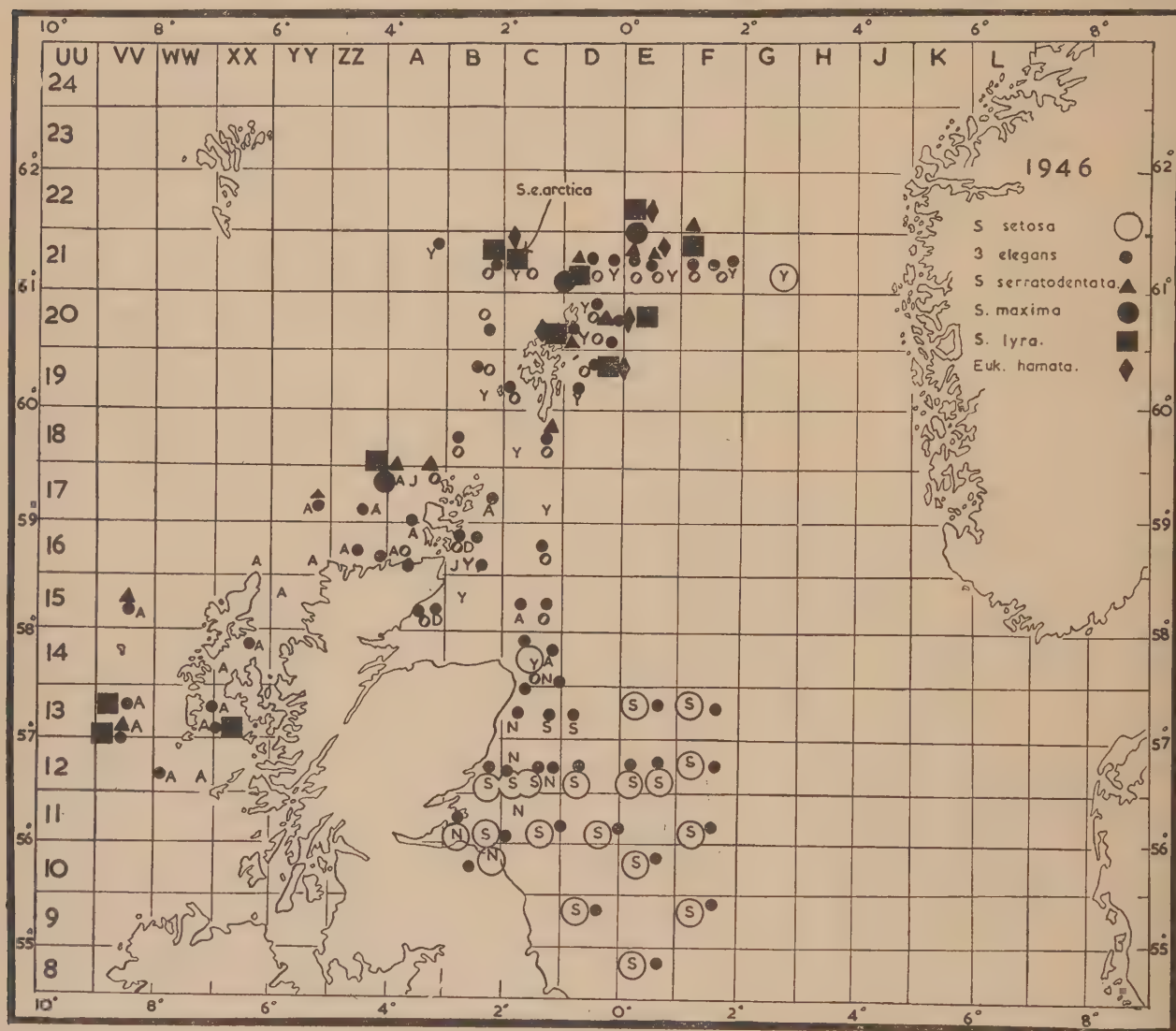


CHART 6

The distribution of Chæto gnatha in 1946

Y=July, A=August, S=September, O=October, N=November, D=December.

longa, *Meganyctiphanes*, *S. maxima* and *Eukrohnia hamata* were most abundant on records 2 and 3 (April, May), but doliolids, *Rhincalanus*, etc. on records 4, 5 and 6 (July/August). Unfortunately these records did not extend sufficiently far west to correlate with Tåning's statement about the colossal influx of warm water to Iceland. In the Scottish plankton samples *Rhincalanus* had a distribution similar to that of doliolids.

The indigenous deep water fauna of the Norwegian Deep was sampled in April when amongst other species *Eucheta norvegica* and *Calanus hyperboreus* were found. The medusæ *Laodicea* and *Cosmetira* whose distribution off the north coast of Scotland, Orkney, Moray Firth, Fair Isle and Shetland in May, June and July was essentially similar, had different origins. *Laodicea* was found in all open ocean waters

examined, *i.e.* from Faroe to off-shore waters west of Barra Head, but *Cosmetira* was only found in abundance in the less off-shore waters such as those south of the Minch, off the north coast and in the Faroe Channel over the Continental Shelf. The waters in the Faroe Channel, however, east of the Wyville Thomson Ridge, became thoroughly mixed so that thereafter the distribution of the two medusæ became similar. Their abundant presence in the Moray Firth region in May, June and July suggests that the

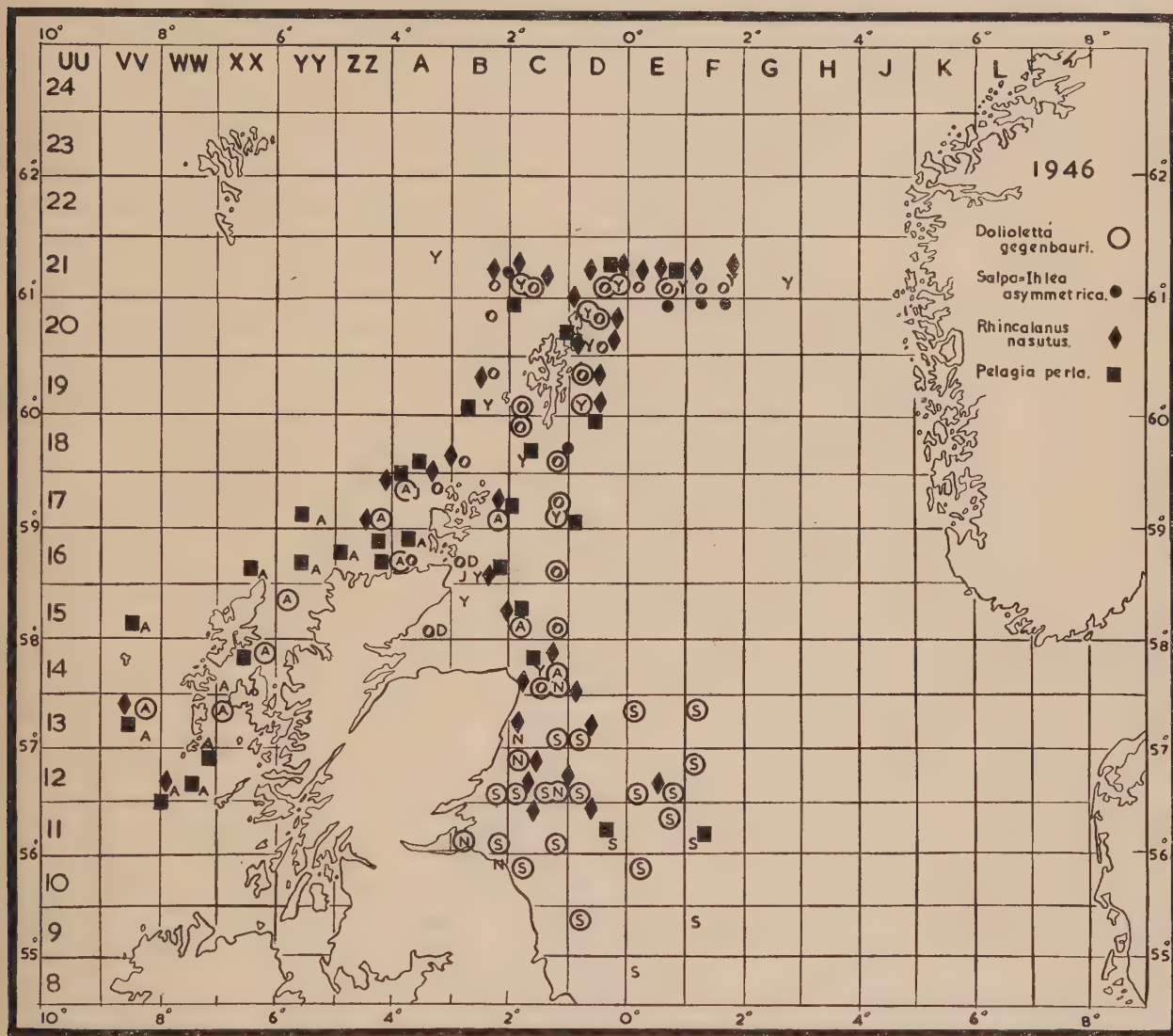


CHART 7

The distribution of other indicator species in 1946

Y=July, A=August, S=September, O=October, N=November, D=December.

north of Orkney passage was then the means of entry. *Obelia* was found also with *Cosmetira* off the west side, but not in the open oceanic water, and it was also much farther distributed in the central North Sea with *S. setosa*; *Obelia* medusæ are of course derived from indigenous hydroids.

1946, Charts 6 and 7

In 1946 the inflow of water through the Faroe Channel was more constantly steady than usual judging from Smed's anomaly figures in his areas "J", "K" and "F" (Smed 1949a and b) and its passage into the northern North Sea was uninterrupted and almost entirely via the north of Shetland (Tait 1948). According to Smed (1948b) the normal inflow into the northern North Sea on the western side of the line 61°N east of

Shetland is 0.3 Km.³ per hour, but in 1946 this had increased to nearly 1.0 Km.³ Because of the absence of influx via the Orkney passages there was no Atlantic water in May in the outer Moray Firth or in the Orkney area in June (Tait 1948), but by September sub-surface waters of the mid-Scottish east coast showed signs of oceanic influence and oceanic water predominated at all depths in October in the north-western North Sea north of 58° except in the Moray Firth.

This condition is well illustrated from the plankton, although no collections were taken in the first half of the year. Warm oceanic species of *Sagitta* (*S. serratodentata*, *S. lyra*) were found off the west of the Hebrides, north-west of Orkney, north-west, north, north-east and east of Shetland but were absent in the Fair Isle passage, Orkney area and Moray Firth. Though there was no sign of arctic Chætoagnatha off the Hebrides *S. maxima* was found north-west of Orkney in August and *S. maxima*, *S. elegans arctica* and *Eukrohnia hamata* were found off the north-west and north-east of Shetland in October. *S. setosa* was dominant in the area to the east of the English and Scottish east coasts in September and November, but by then *S. elegans* had also penetrated the area. The absence of sampling from the first half of the year and from the whole year over most of the central and northern North Sea areas limits the picture available from Scottish collections but through the kindness of Mr. K. M. Rae (of the Oceanographic Laboratory, Leith) the unpublished Continuous Recorder results have been made available to me and these entirely support the above contention. *S. setosa* was dominant and *S. elegans* almost absent on the Leith-Copenhagen line, especially in May, June and July, but by August, although *S. setosa* was still dominant, there was a marked increase in the number of *S. elegans* to the east of the Moray Firth and east Scottish coasts. By September and October *S. elegans* had almost completely replaced *S. setosa* in the whole western half of the northern North Sea (see also the report by Lucas, 1949a, of this work).

This excellent correlation is further supported by other plankton indicator species such as salps and doliolids, Rhincalanus, Eucalanus and *Pelagia perla* for the warm oceanic water and by Meganyctiphanes and *Euchæta norvegica* for the boreal water. *Pelagia perla* was more abundant in 1946 in Scottish waters than in any year, at least as far back as 1920, and its distribution in the area followed the course of the Atlantic inflow. It was distributed at almost all stations off the west coast in August, the earliest sampling there, and probably much earlier as it had already by July become abundant west, north and east of Shetland, east of Fair Isle; east of the Moray Firth in August, and as far south as the east Scottish coast extending off the Northumberland coast in September. It was not found in the Moray Firth in July, October or December and it was only very rare to the east of Pentland. *Pelagia perla* died out in the northern North Sea by November.

Almost identical was the distribution of Rhincalanus and Eucalanus, except that Rhincalanus being more tolerant persisted at least until November. A few specimens of *Eucalanus crassus*, unusual in the Scottish area, were taken east of Shetland in July and east of Scotland in September. *Doliolletta gegenbauri* was similarly distributed and both oozoids and gonozoids were found, the latter as small individuals that had reproduced in the North Sea area in summer but which had almost all died out by November. The oozoids, however, persisted in the old nurse stage and were taken in the area off the east Scottish coast as far south as 55°30'N in September and in the Firth of Forth estuary in November. Mr. J. G. Cattley (private correspondence) also reports oozoids from 54°12'N 00°20'E on 20th November. Salps were not abundant in 1946 but *Ihleia asymmetrica* was taken north-west of Shetland in July and north-east and south of Shetland in October.

The boreal forms *Euchæta* and Meganyctiphanes also entered the northern North Sea area by the route north-east of Shetland but like *S. maxima* and *Eukrohnia hamata* were only taken in October collections.

1947, Charts 8 and 9

For 1947, Smed's spring surface temperature figures are lower than usual for recent years but started to rise in May and are very high indeed in July, August and September, especially in area "F" (north-western North Sea) where positive anomalies of 2.8°C. were obtained in August. The anomalies thereafter fell to near normal by the end of the year (Smed 1949a and b). Tait (1949a p. 61) states that a small tongue of oceanic water was found immediately north of Shetland, but on the rest of the 61°N line from Shetland to Norway there was no evidence of oceanic inflow. Hermann (1949a p. 8), from observations in July 1947, argues an inflow into the Faroe-Shetland Channel only in the south-east section and an outflow

in the north-west, whereas for 1946 (Smed 1948a) the outflow was in the middle rather than the north-west. Tait further suggests that the oceanic water present in the Faroe Channel was blocked by a southerly extension of the boreal waters from the Norwegian Sea. During the period from July to December only in the north-west corner of the North Sea was the salinity greater than 34.99‰ and he considered that the high surface temperatures were due to solar radiation, as the bottom layers were cold, so that the

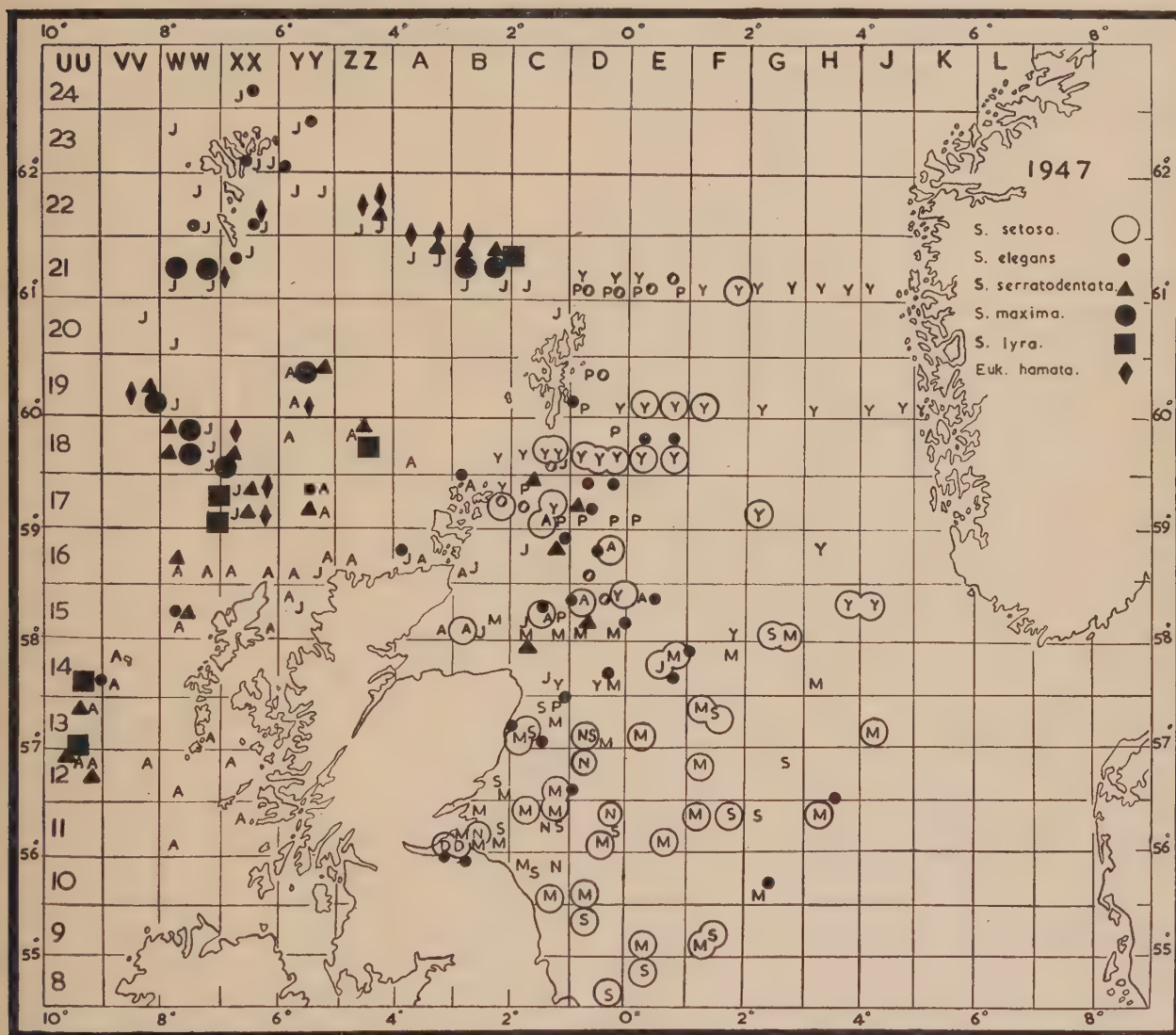


CHART 8

The distribution of Chaetognatha in 1947

P=April, M=May, J=June, Y=July, A=August, S=September, O=October, N=November, D=December.

part of the North Sea south of Fair Isle had positive temperature and negative salinity anomaly. Thus there is a picture of the oceanic influx entering the Faroe Channel at the south side only, to some extent reaching Shetland and infiltrating slightly round the north of Shetland, but on the whole held up by arctic water so that the normal inflow on the 61°N line was absent, thus barring the oceanic water from the North Sea.

The excellent correlations between the plankton and the hydrography seen in 1946 are again evident in 1947. *S. setosa* was well distributed in the north-western North Sea during the summer and had almost entirely replaced the usually abundant *S. elegans* population there, including the area to the immediate east but not west of Fair Isle. Although even present on the 61°N line between Shetland and Norway at

about 2°E, it was absent in the north-west corner where Tait described a small influx, and it is significant that *S. lyra* was found to the north-west of Shetland in June having otherwise been taken only off the west Scottish coast at the only time of sampling there in August.

The presence of the boreal waters in the area is shown by *S. maxima* and *Eukrohnia hamata* which were found in unusual abundance on both the Faroe-Shetland and Faroe-Hebrides lines, though in view of Hermann's statement mentioned above, it is significant that *S. maxima* was not found at the southern stations of the Faroe-Hebrides line. *S. serratodentata*, which was found in the oceanic water outside the North Sea, had only succeeded in penetrating to the area east of the Moray Firth in April and May, not by the route via north of Shetland, but evidently by the route to the immediate north of Orkney, to be recorded in April at C17a, C17d and D17c, and in May at C15c and D15c. *S. elegans* was unusually scarce in the north-western North Sea in 1947.

Salps were scarce in 1947 and only found in the Faroe Channel in August, but doliolids, though not abundant, were in sufficient numbers to illustrate their indicator value. They were taken at the south end only of the Faroe-Hebrides line and at the extreme south-east end of the Faroe-Shetland line in June, with a single October record to the immediate east of Shetland. They were also taken in the Faroe Channel in August, and in the same month were found north of Orkney and east of Pentland. By September they were found distributed over the area south of Fladen and off the east Scottish coast and they continued to be found off the north English coast in October and November. The English research vessel *Sir Lancelot* found them in October at the stations indicated on the chart (I am indebted to J. G. Cattley for details of these catches).

The evidence from the doliolids is supported by the distribution of the copepod *Rhincalanus* and the medusæ *Cosmetira*. The former was found widely distributed in the Faroe Channel in June but was absent on the 61°N line and in the whole area of the North Sea east of Shetland and Fair Isle in July. On the other hand, it was present west of Fair Isle, north and east of Orkney in July, Moray Firth in August, Fladen and off Aberdeen in September and off the north English coast in November.

Cosmetira had presumably already passed the entrance to the Faroe Channel when sampling was carried out in June, but it was by that time found on the Faroe-Shetland line at the south-east end only and close inshore along the north coast of Scotland. It was also found on both sides of the Pentland Firth by which route it had apparently already reached the Moray Firth. In July it was found north-east of Shetland with a few specimens also east of Shetland and it was also found at the western four stations only (where *Obelia* was absent), on the line through the Fair Isle passage, but not at the eastern four stations (where *Obelia* was present). *Obelia* is here significant in that its distribution is coastal irrespective of temperature or salinity and so it was found abundantly off all the west, north and east Scottish coasts but was absent in areas where coastal waters were displaced by (not mixed with) oceanic water.

Thus Tait's theory (1930, 1931, 1934, 1937) that the Fair Isle passage generally cannot be regarded as a through route of the Atlantic influx is amply borne out. On the west (oceanic side) we find *Cosmetira* and *Rhincalanus* and on the eastern side we find *Obelia* medusæ and *S. setosa*, with only a small area of overlap at about Fair Isle. South of Fair Isle and to the immediate north of Orkney we find that there is a route of inflow in 1947 transmitting *Fierasfer* larvæ, *S. serratodentata*, *Cosmetira*, *Rhincalanus* and doliolids.

It would appear that the oceanic forms entering the North Sea by the Orkney passages in 1947 were not carried there by a vast influx of water but rather that those few organisms that had come that way were later well distributed over the north-western North Sea area. The doliolids which were found in quite large numbers had been stimulated by the warm surface temperature to breed so that a few oozoids had produced numbers of gonozoids which had not themselves been brought in from the Atlantic. Such an increase in oceanic species in the North Sea, without a large influx of oceanic water, could only occur among forms such as doliolids which are tolerant to relatively low salinity conditions but which require a suitable high temperature to thrive. It will be remembered that 1947 was an exceptionally warm summer which of course warmed the surface waters only.

Other exotic forms, including *S. lyra*, the larvæ of fish such as *Stomias*, *Paralepis*, *Nansenia*, *Bathylagus*, *Fierasfer*; the pteropods *Clio pyramidata*, *C. cuspidata*, *Diacria trispinosa*; the siphonophores *Physophora*, *Galettia australis*, *Chelophyes appendiculata* and *Lensia conoidea*, occurred in the entrance to the Faroe Channel and were concentrated at the Scottish ends of the line. Of these only the less extreme forms, *Clio pyramidata*,

Physophora, Chelophyes, doliolids and Rhincalanus reached the north-west of Shetland and only Physophora reached the north-east of Shetland, though Clio and Chelophyes were also found over the Norwegian Deep.† The presence and extent of arctic water is illustrated by the cold water species—*Calanus hyperboreus*, larvæ of *Sergestes arcticus* and the larvæ *Myctophum arcticum* and *M. glaciale*—the distribution of which extended about the full length of both the Faroe-Hebrides and Faroe-Shetland lines, and by *Calanus hyperboreus* which was found to the immediate east of Shetland in April.

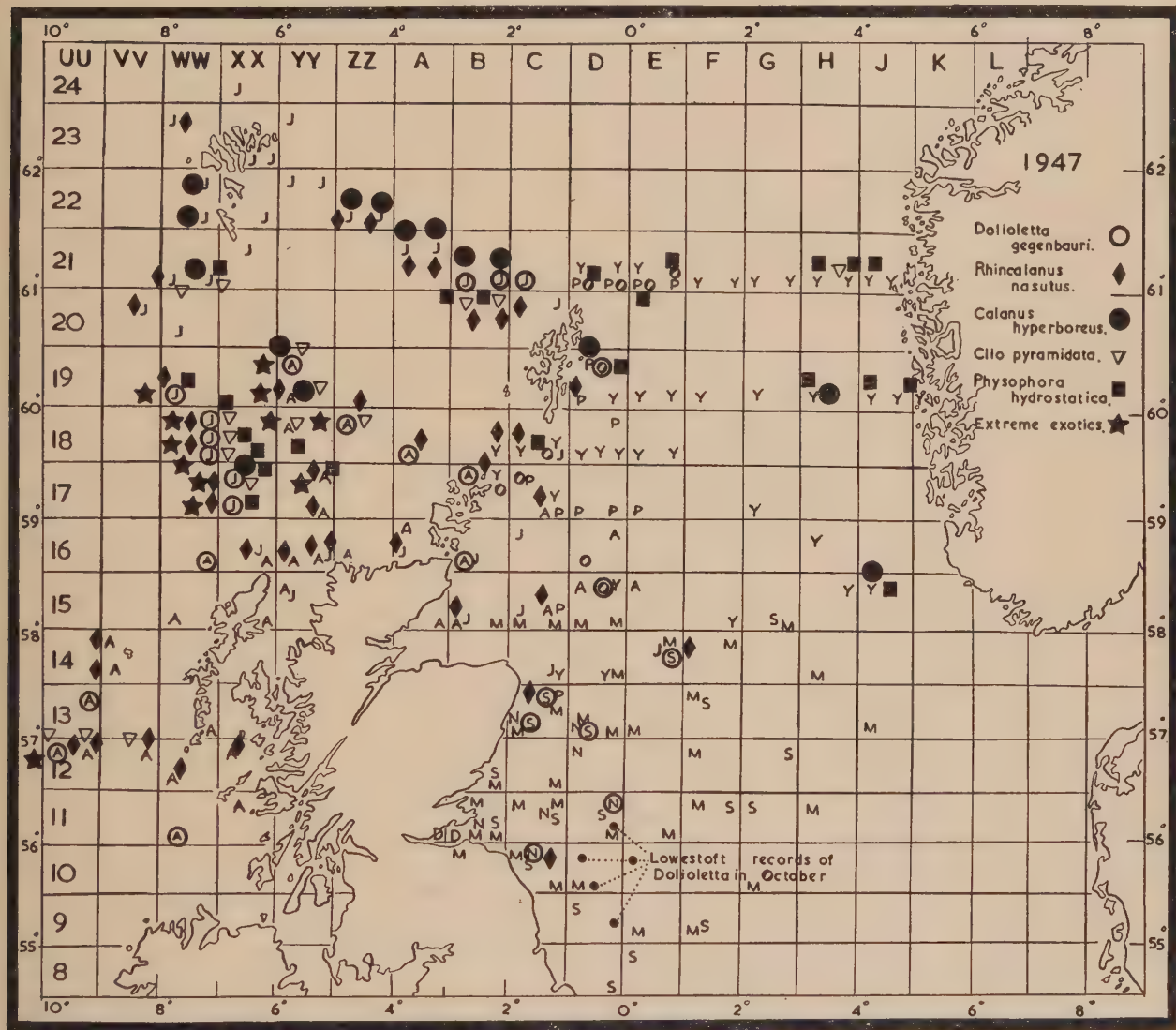


CHART 9

The distribution of other indicator species in 1947

P=April, M=May, J=June, Y=July, A=August, S=September, O=October, N=November, D=December.

We have therefore sufficient evidence from the distribution of plankton indicator species alone to postulate a theory that in 1947 there was a tongue of oceanic water penetrating the Faroe Channel at its southern side while the northern side contained an admixture of cold water which prevented the bulk of the oceanic water from reaching the Faroe-Shetland line so that only a small proportion of the reduced amount reaching Shetland penetrated the North Sea east of Shetland. There was however a leakage of the pressure of the oceanic water into the North Sea via the immediate north of Orkney, and this water became distributed over the whole Scottish east coast area south of 59° where it was mixed with warm surface waters. There was no inflow of water via the passage north of Fair Isle. This picture agrees very

well with that produced by the hydrographers with the additional evidence of the Orkney leakage which might be a small amount of water compared with the North Sea and so easily hidden by the rapid rise of temperatures there due to solar radiation.

[The 1947 data given here were used in a paper presented to the International Council of the Exploration of the Sea at the meeting in Amsterdam, 1951, and as such have now been published. (Rapp. et Procès-Verbaux, Vol. CXXXI, 6, 1952.)]

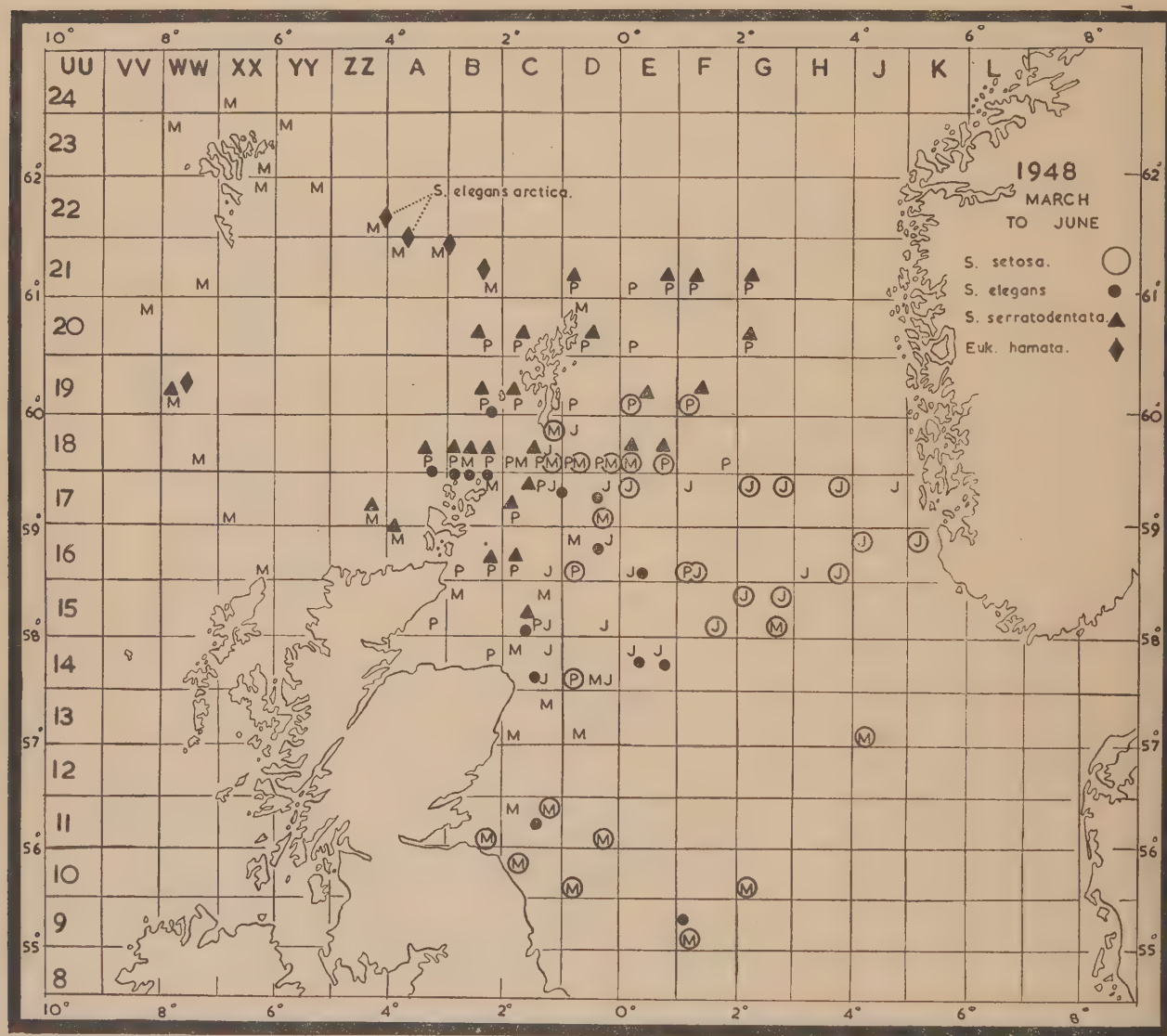


CHART 10

The distribution of Chæto gnatha from March to June, 1948

P=April, M=May, J=June.

1948, Charts 10, 11 and 12

Smed's figures for 1948 show that the monthly anomalies of surface temperatures in his areas "J" and "K" were higher in the first six months of the year (except for the area "J" in January) than in the second six months, and in area "K" the figures from July to October show a negative anomaly. Hermann (1949b) shows that the Atlantic water flowed to the Norwegian Sea north of Farø, in approximately the same magnitude as through the Farø Channel and his figure 21 clearly shows that in the Farø Channel, between Farø and Shetland, the current was at its strongest near Shetland. There was also shown a tongue of cold water east of Iceland which also affected the area north of Farø and which showed distinct signs of

penetrating the Faroe-Shetland line on the Faroe side (Hermann, figure 16). The Scottish investigations (Tait 1949b p. 53) show that, following the release of the hold-up of Atlantic water towards the end of 1947, the influx subsided in January 1948 to revive again in March, and then became weak again during the summer. Drift bottle returns indicate that the main path of the inflow into the North Sea was by the north of Shetland during April, May and probably later, and that there were circulatory water movements

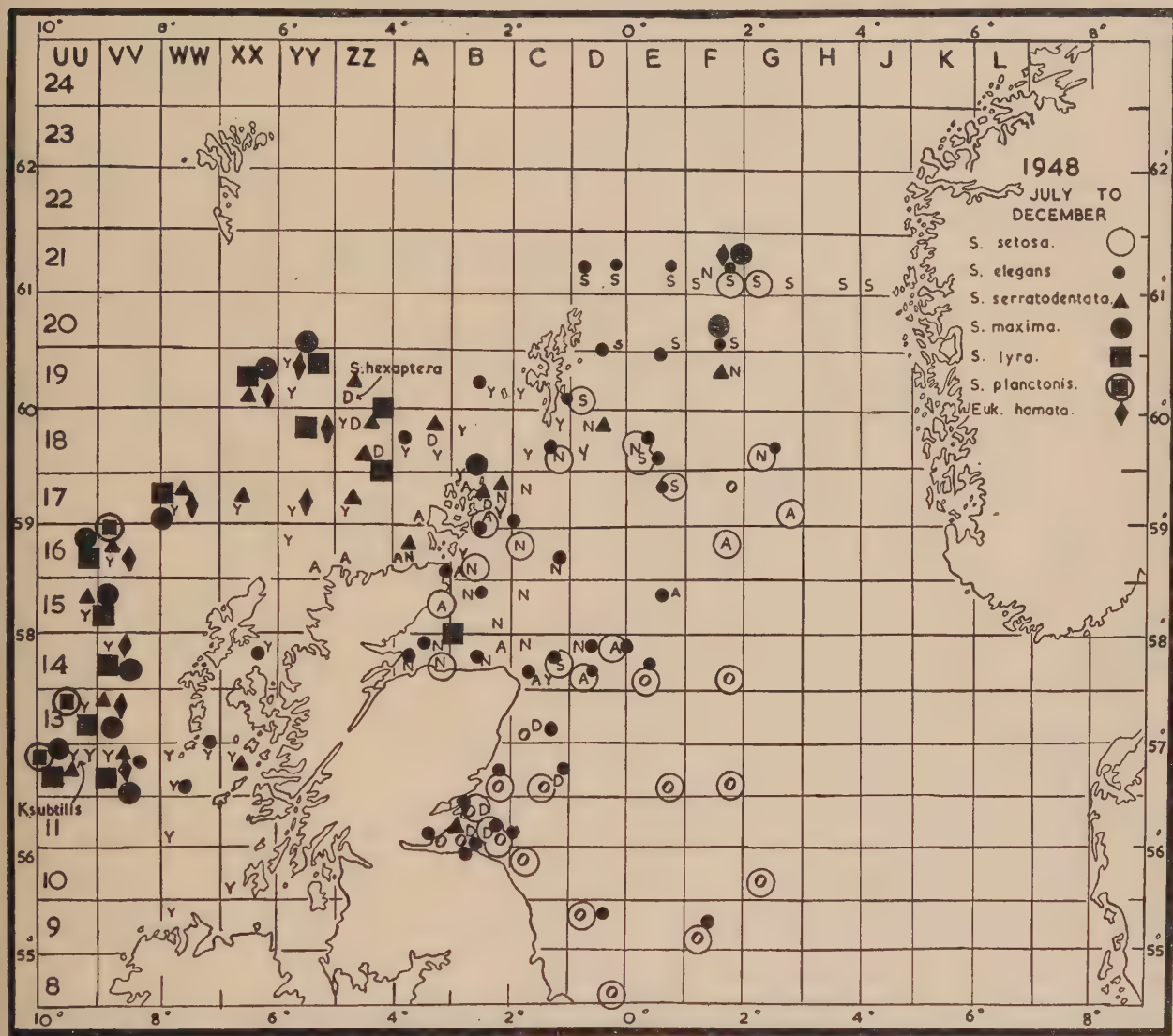


CHART 11

The distribution of Chætognatha from July to December, 1948

Y=July, A=August, S=September, O=October, N=November, D=December.

embracing the north-western North Sea region from the Moray Firth to 61°N from April to August inclusive. There is also evidence from drift bottles of the influx of "coastal or bank waters" to the north-west region between Fair Isle and Orkney and it is apparent that this influx extended considerably to the east and south-east of Orkney and well into the Moray Firth. Later in the year there was a marked increase in drift bottle recoveries from the north-eastern side of the North Sea and an absence of recoveries on the west side south of 57°30'N. Higher temperatures and salinities prevailed over a wide area of the central North Sea in October. A tendency for the temperature and salinity data to show a decline in November and December was evident in the north-western North Sea, but observations to the north-west of Orkney in

the latter half of December indicate that an abnormally strong Atlantic current passed through the Faroe-Shetland Channel in the autumn-winter period.

The hydrographical deductions are amply borne out by the plankton indicators during the year. This has already been given in some detail by Fraser and Saville (1949a). The tongue of cold water influencing the Faroe-Shetland line is shown by the presence there in May of *S. elegans arctica*, *Calanus hyperboreus* and

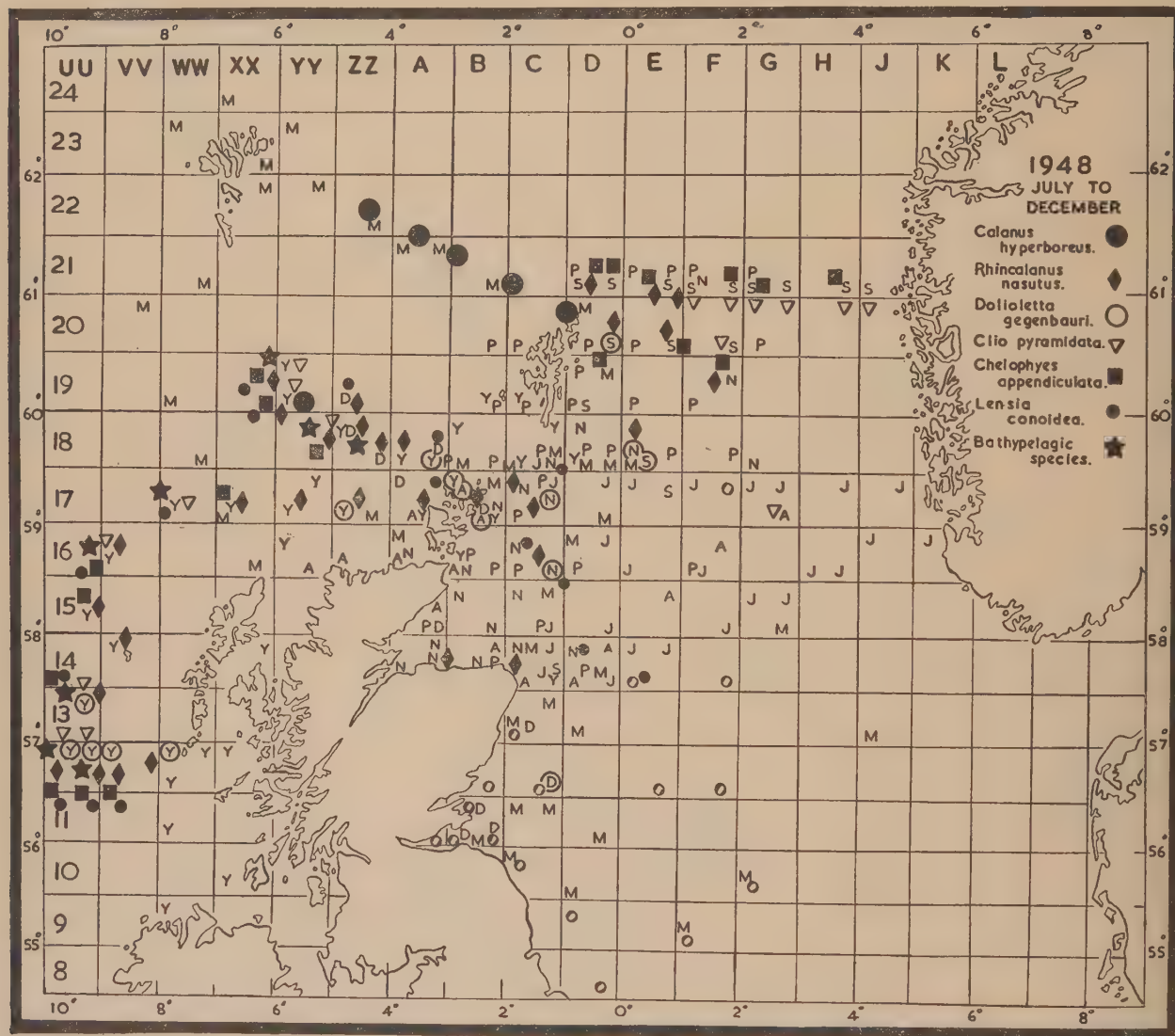


CHART 12

The distribution of other indicator species from July to December, 1948

Y=July, A=August, S=September, O=October, N=November, D=December.

Eucheta norvegica, none of which were taken on the Faroe-Hebrides line at that time. The main spring inflow round the north of Shetland is illustrated by the presence of *S. serratodentata* in April to the west, north, north-east, east and south-east of Shetland and the circulatory movements described by Tait carried *S. setosa* to the area east of Fair Isle and Sumburgh in April, whilst there was a mixture of *S. serratodentata* and *S. setosa* at the edge of this area. The influx by Fair Isle-Orkney is also shown by the distribution of *S. serratodentata* which was found west of Fair Isle (but not at the first two stations east of Fair Isle) and also to the east of Orkney, east of Pentland and in the Moray Firth.

The main summer inflow into the Faroe Channel is clearly shown by the abundance of exotic species (see Fraser and Saville, 1949b), including *S. lyra*, *D. gegenbauri*, *Lensia*, *Clio*, *Diacria*, etc., of warm origin,

mixed with species upwelled from deep cold water such as *S. maxima*, *Eukrohnia hamata*, *Sergestes* larvæ, bathypelagic copepods and fish larvæ which were entering the Faroe Channel in July. Rae (1949) says that *S. maxima*, accompanied by *Eukrohnia hamata*, occurred in the north-western part of the area sampled by Continuous Recorder in May and June and the south-eastern boundary of this population was sharply defined giving way to the warmer water species *S. serratodentata* (together with the copepod *Rhincalanus*

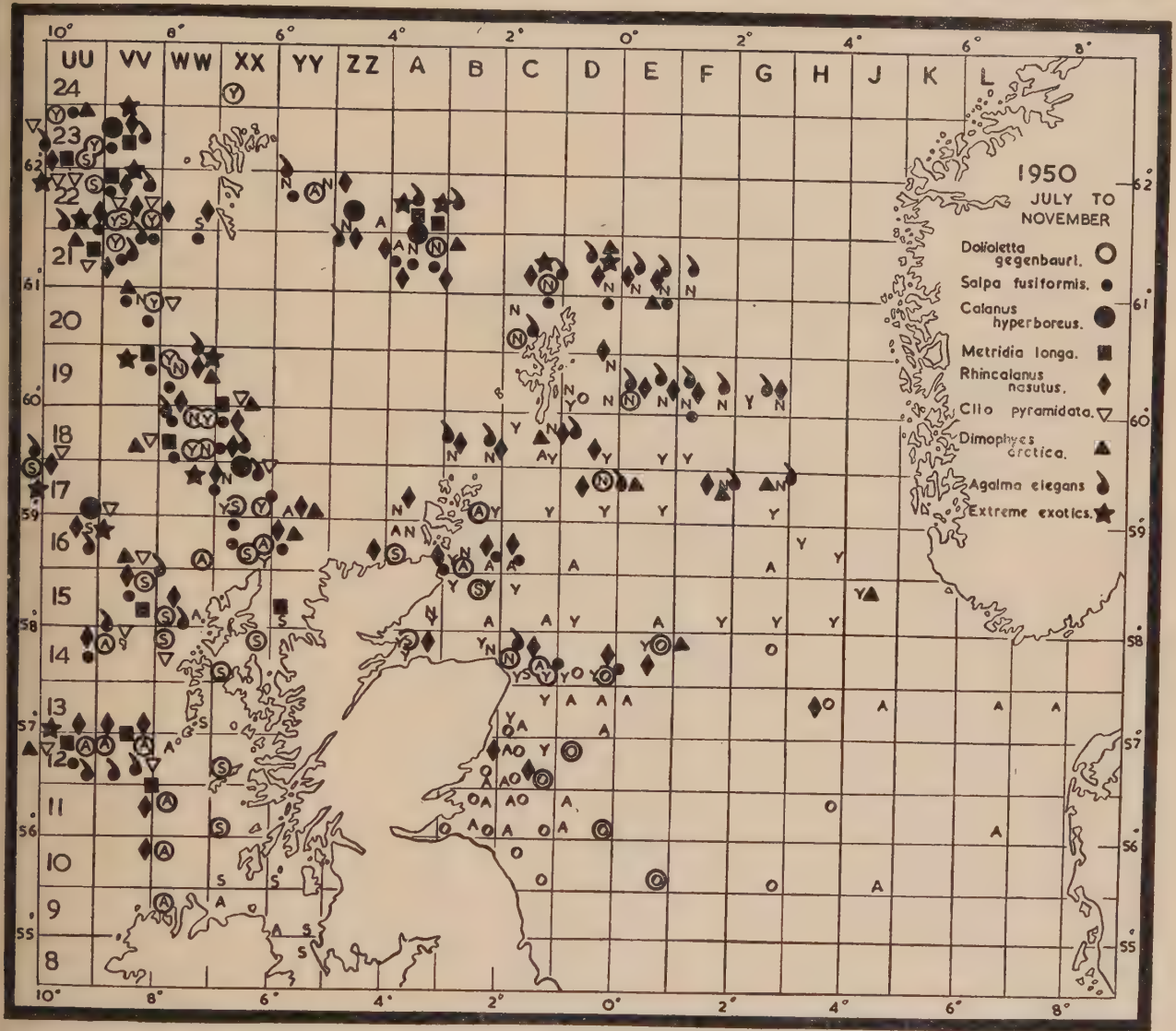


CHART 13

The distribution of Chatognatha from January to June, 1949

Z=January, F=February, R=March, P=April, M=May, J=June.

nasutus) some 250 miles south-east of the Iceland coast. In the inshore waters to the coastal side of the 200 fm. contour he found *S. elegans* was dominant. The course of the exotic forms is uncertain as there was no sampling of the Faroe-Shetland line after May, but the north of Shetland route is probable. Rae (*ibid.* p. 60) says that the occurrence of *S. maxima* on the "A" route in June and of *S. serratodentata* on the "K" route in August and September, when compared with previous Continuous Recorder results, suggest unusual Atlantic influence in the North Sea. *S. maxima*, *Eukrohnia hamata*, *Chelophyes* and *Rhincalanus* were found on the 61°N line and penetrating the North Sea to the east of Shetland. Significant in connection with Tait's statement about concentration on the east side of the North Sea is the fact that these exotics on the 61°N line were mostly taken east of 1°E. The absence of drift bottle returns on the western side of the

North Sea south of $57^{\circ}30'N$ can be correlated with the presence of *S. setosa* near the coast from $57^{\circ}N$ southwards in October and December and its relative absence north of 57° . The presence of at least some oceanic influence is shown by the sampling of *S. serratodentata* in the Firth of Forth in October and *D. gegenbauri* off the east Scottish coast in December. The strong Atlantic current in the Faroe Channel in the latter half of December is amply borne out by the plankton content as *S. lyra*, *S. hexaptera*, *S. maxima*, *Lensia*,

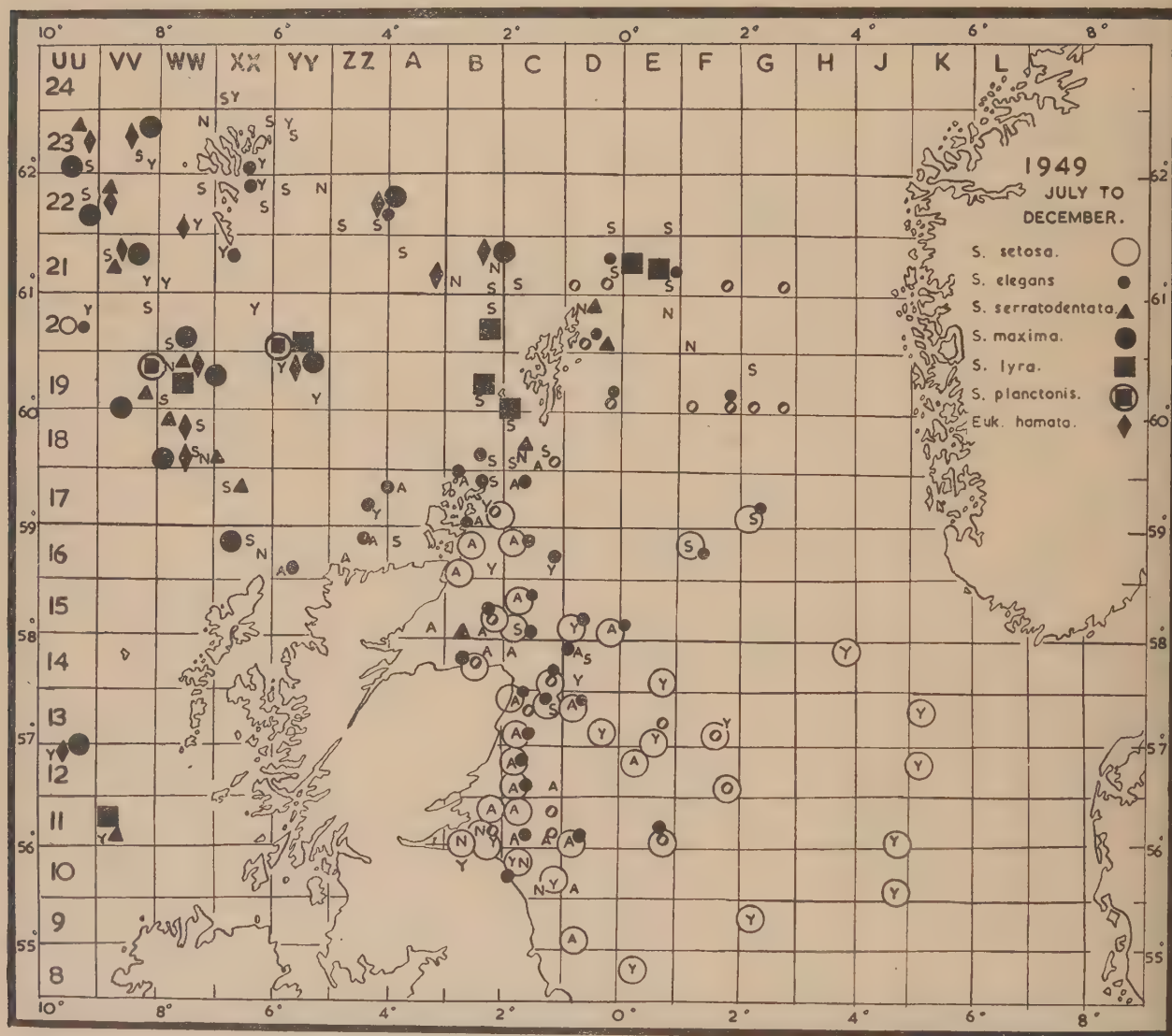


CHART 14

The distribution of Chætonotha from July to December, 1949

Y=July, A=August, S=September, O=October, N=November, D=December.

Clio, *Rhincalanus*, etc. (see Fraser and Saville 1949b), were found there. Further, the fact that this concentration of oceanic water was affecting the Moray Firth and Orkney areas is shown by the presence of *S. serratodentata* in November and December west of Orkney, by *S. lyra* taken in the Moray Firth in November and *D. gegenbauri* and *Rhincalanus* in or near the Moray Firth in November. Rae shows a sharply marked increase in the number of *Clio* on the "A" line (from Aberdeen to Shetland) in August and September; on the "V" line (north of Scotland to Iceland) *Clio* increased at the same time following an increase a month earlier on the "X" line (about 200 miles farther south), and on the "V" line *S. maxima* was most common in August, September and October.

1949, Charts 13, 14 and 15

Tait (1950) reporting on the hydrographic conditions says that the last quarter of 1948 was marked by a considerable inflow into the northern North Sea which tended to wane towards the end of the year but nevertheless continued into 1949, strongly during the first two months of the year. The inflow affected the eastern rather than the western North Sea, not only in the beginning but throughout the year and even the

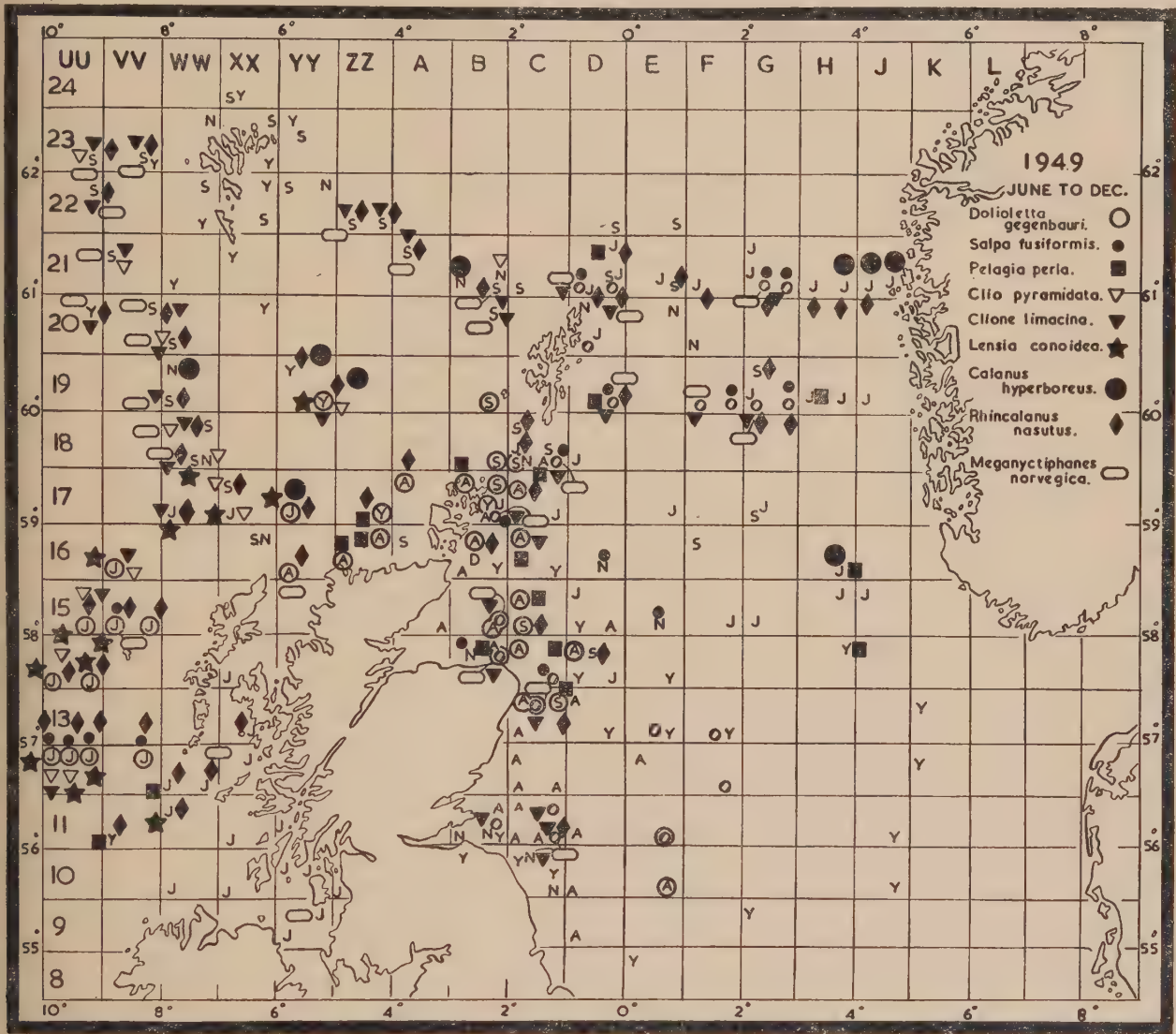


CHART 15

The distribution of other indicator species from June to December, 1949

J=June, Y=July, A=August, S=September, O=October, N=November, D=December.

first three months of 1950. The current into the North Sea was at a minimum in March thereafter increasing again. Drift bottle returns from May to August on the Schleswig Holstein coast may safely be taken as indicative of strong oceanic influence from the north pushing far down into the North Sea. Oceanic influence in the northern North Sea off the Norwegian coast reached a minimum in the last month of 1949 and thereafter revived again in March 1950.

Positive temperature and salinity anomalies were recorded on the Dogger Bank in January 1949 but they were mainly less positive in March, although between 60° and 61°N they were still decidedly positive so that the decline, though distinct, was a relatively small one. High temperatures (over 10°) and salinities (over 35.4‰) were found south of the Wyville Thomson Ridge in May and the salinities were also

highly positive in June east of 2°E as far south as 58°50'N. In July there was evidence of oceanic water on the northern edge of the Dogger Bank underlying a fresh upper layer emanating from the Skaggerak, and of a wide superficial extension westward to 1°E of Baltic and Skaggerak effluent from mid-June to September. In the western North Sea, however, values were about normal though increased somewhat in December west of 1°W between the Firth of Forth and the northern part of the Moray Firth.

The water north and south of the Wyville Thomson Ridge in May, September and November showed distinct differences in oxygen content characteristics. North of the Wyville Thomson Ridge the oxygen value increased with depth to a constant value at about 200 m., while south of the Ridge the oxygen diminished with depth. Slight differences in phosphate content between the two areas are also reported. The final paragraph of Tait's report reads "no apparent connection is to be deduced so far between oxygen and phosphate distributions although there is evident in the Faroe Channel area, as above indicated, differential distributions in both characters (oxygen and phosphate), (a) as between the north and south of the Wyville Thomson Ridge and (b) the north-western and south-eastern halves of the Faroe-Shetland section."

The Scottish plankton collections taken in 1949 have previously been described and their relations with hydrological conditions discussed (Fraser, 1950). That the early inflow of Atlantic water affected the eastern rather than the western North Sea is well illustrated by the presence of *S. serratodentata*, *Rhincalanus*, *Thysanæssa longicaudata* and *S. elegans* towards the entrance to the Skaggerak in January and April and the general tendency for *S. elegans* to be distributed more on the eastern side of the North Sea in spring than in summer or autumn. (The deep water indigenous fauna of the Norwegian Deep was also sampled and contained *Meganocyttaphanes*, *Euchæta*, *Gaidius*, *Heterorhabdus*, *Metridia longa*, *Scina borealis* and *Stylocheiron elongatum* in January.) Though present in spring, *S. serratodentata* was apparently absent there in July though it had a widespread distribution over the northern North Sea, Faroe and west coast areas, generally in small numbers until late summer, showing the extent of the winter inflow north via Shetland.

The hydrographic statement that the temperature and salinity anomalies were positive south of the Wyville Thomson Ridge in May and in June east of 2°E as far south as 58°50'N is clearly supported by the distribution of *S. lyra*, which was found south of the Wyville Thomson Ridge at the end of April as well as off the west coast in June, and which was taken north-east of Shetland and in G. 19 in June. There is additional supporting evidence from the distribution of *Rhincalanus* and *Pelagia perla*. The statement about the evidence of oceanic water at the northern edge of the Dogger Bank in July, underlying a fresh upperlayer, is illustrated by the presence there of *D. gegenbauri* in August underlying *S. setosa*, and that this condition persisted is shown by a similar distribution of both these species in October. The increase in anomaly off the east Scottish coast at the end of the year is amply borne out by the plankton, in which *Salpa fusiformis* and *Muggiæa* were found there in November and December whilst *Clione* and *Rhincalanus* were present as far south as the Firth of Forth in October and November.

That the water north of the Wyville Thomson Ridge had different characteristics from that south of the Ridge, as shown by Tait from physical and chemical analyses, is emphasised in the same Volume of *Annales Biologiques* by Fraser (*ibid.* p. 94) from the plankton records. He suggested that these two streams in the middle and late summer at least, each very distinct in itself, mixed along the line of meeting. Of these the southern one was a Lusitanian stream originally containing *S. lyra*, doliolids, *Pelagia perla*, *Mitrocomella*, *Lensia*, *Chuniphyes*, *Vogtia*, *Praya* and *Rosacea*; it entered the Faroe Channel south of the Wyville Thomson Ridge, and along the edge of the Continental Shelf and penetrated the northern North Sea round Orkney. The other was an Atlantic stream, much richer in *Calanus* and other crustacea, and containing also *Salpa fusiformis* (which was abundant in the area north of 58°N 12°W not included in the chart), *Clione*, *Dimophyes arctica*, *Agalma*, *Laodicea*, *S. maxima* and *Eukrohnia hamata*. This stream entered the Faroe Channel at its northern side and penetrated the northern North Sea via the north of Shetland. Many typical oceanic forms were of course common to both streams, e.g. *Aglantha*, *Clio*, *Rhincalanus*, *Eucalanus*, *Thysanæssa longicaudata*, *S. planctonis* and to some extent *S. lyra* and *S. maxima*. The Lusitanian stream of organisms started somewhat earlier than the western stream, and it affected the area east of the Moray Firth in August and September, while those organisms entering via north of Shetland did not arrive until October and November, although to some extent the northern stream had by then absorbed Lusitanian fauna such as *S. lyra* by mixing. Two records of *Muggiæa atlantica* were made in November and

December east of Pentland and in the Moray Firth, and indicate that the Lusitanian stream was still effective in that area at the end of the year.

Records of *S. setosa* in the Minch area in June suggest that outflowing water from the Irish Sea via the north channel can penetrate to that distance and the records are interesting in view of the presence of *S. setosa* in the Clyde in March reported by Barnes (1950) who also attributes their origin to Irish Sea outflow.

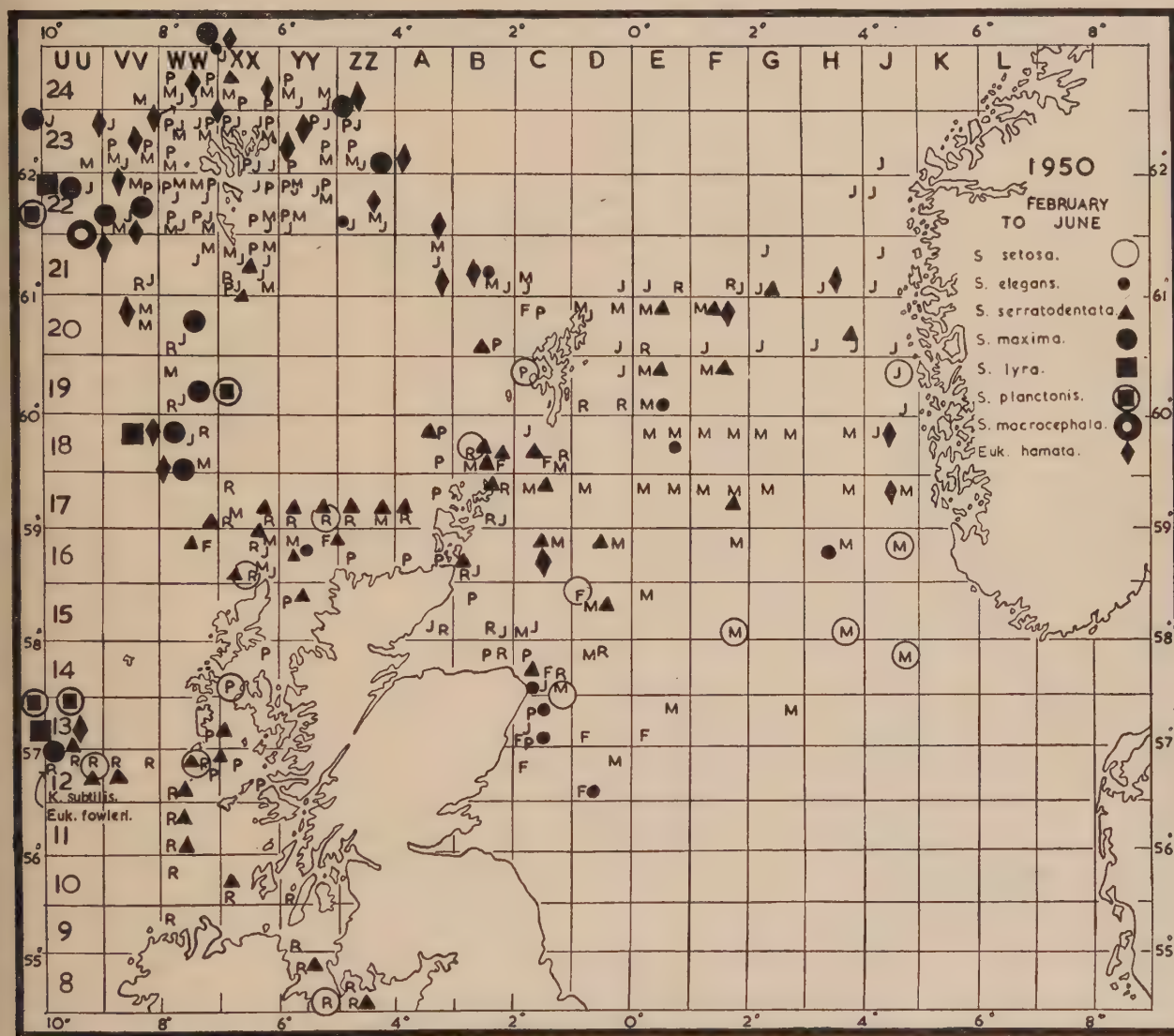


CHART 16

The distribution of Chatognatha from February to June, 1950

F=February, R=March, P=April, M=May, J=June.

1950, Charts 16, 17, 18 and 19

The oceanic influences in the Scottish area in 1950 were very different from those of 1949 and as a brief description of the conditions existing I quote the last two paragraphs from Tait (1952) "to sum up, 1950 was clearly a year of relatively poor oceanic influence in the northern North Sea. A weak spring current through the Faroe-Shetland Channel in March really affected only the northern reaches of the North Sea, and rather in the eastern than the western half of the region. The intensity of the incursion tended slowly to retract during the summer and revived only weakly in the autumn.

"Westward of the British Isles to longitude 20°W there was apparent a bifurcation, approximately along latitude 55°N, in the eastward tending surface current from the north-eastern Atlantic Ocean. Southwards from this latitude a southerly component gradually intervened, while the opposite recurred northwards from latitude 55°N. By the evidence available these directions would appear to have contained stronger east and south components during 1950 than are generally the rule."

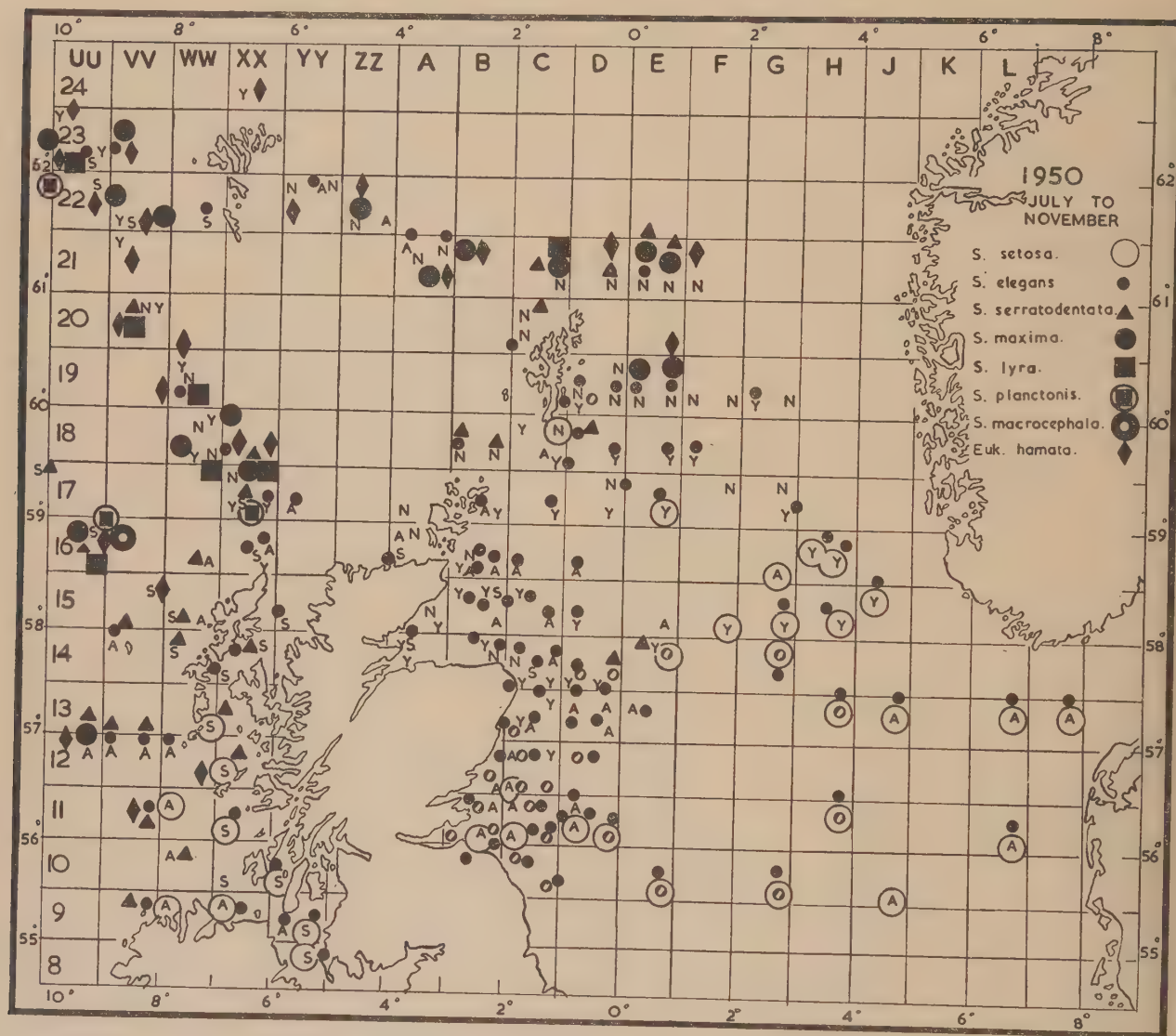


CHART 17

The distribution of Chatognatha from July to November, 1950

Y=July, A=August, S=September, O=October, N=November.

One of the most unusual features of the distribution of *Sagitta* species in 1950 is a spring extension of *S. setosa* into the area west of Shetland and Fair Isle where one or two specimens only were obtained. At the same time this species, as in 1949, extended northwards from the Irish Sea towards the Hebrides where a few specimens were taken. Two collections, one north of the Butt of Lewis and one north of Cape Wrath, also contained *S. setosa* and in view of the presence of *S. setosa* in the Minch in 1949 it would seem more probable that these few specimens could be linked with the west coast distribution rather than with the North Sea. This is supported by the presence of *S. serratodentata* at all the north coast stations in February and March, indicating that although the influx was probably weak, Atlantic water was present there and penetrated to the area east of Moray Firth by the Orkney passage and to the area east of Shetland via

Flugga. The *S. setosa* referred to above, west of Shetland and Fair Isle, could have been taken westwards through the Fair Isle-Sumburgh passage at the same time as the Atlantic water penetrated eastwards via Fair Isle-Orkney passage. Although the distribution of *S. serratodentata* in the North Sea was confined to its northern reaches the plankton of the whole area of the east Scottish coast was still showing the effects of the 1949 influx. *Rhincalanus*, *Thysanæssa longicaudata*, *Euchæta hebes* were found off the Firth of Forth in January and the whole area was dominated by *S. elegans* and almost free of *S. setosa* until late summer and autumn.

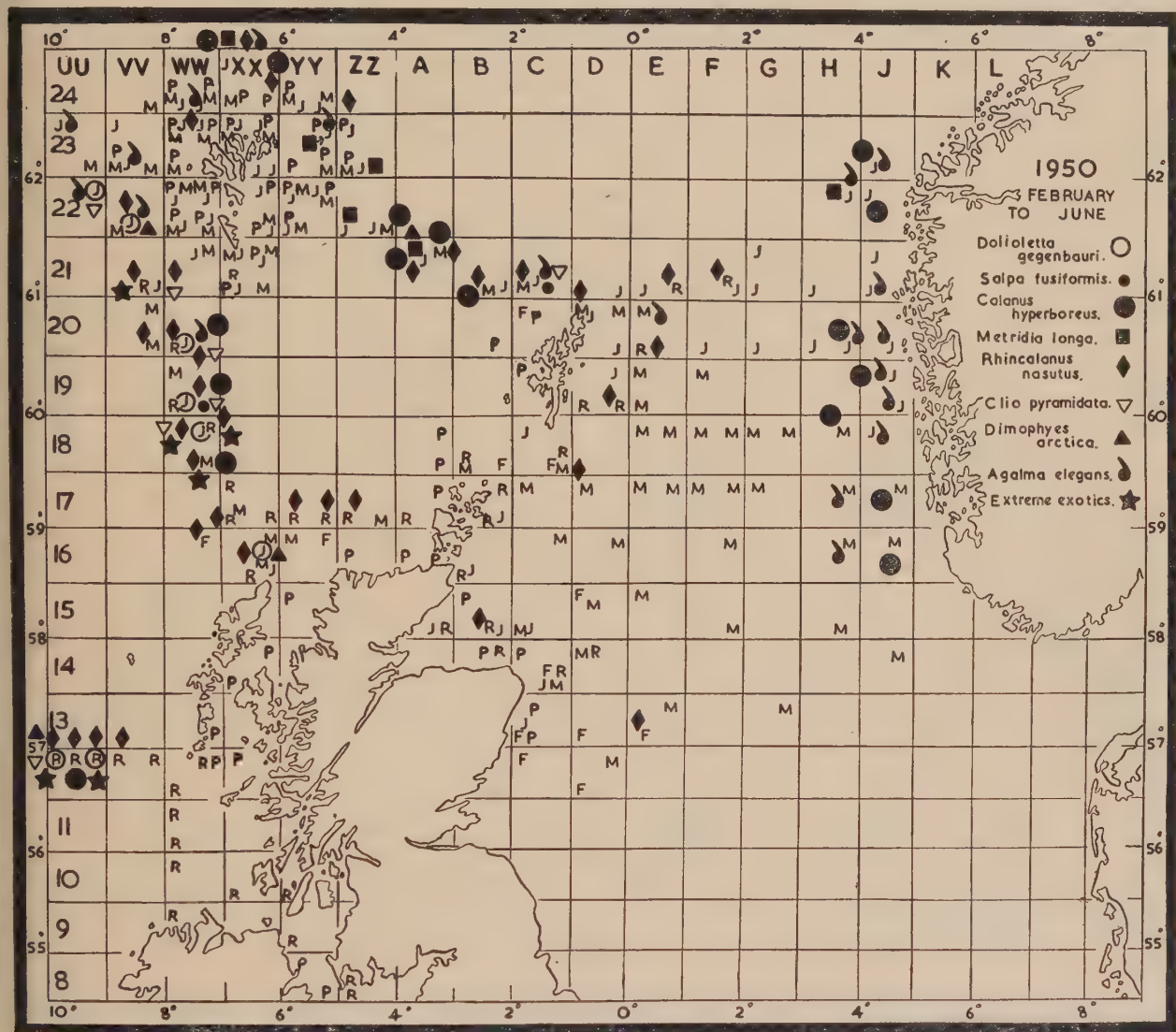


CHART 18

The distribution of other indicator species from February to June, 1950

F=February, R=March, P=April, M=May, J=June.

The weak spring Atlantic influx through the Faroe Channel was apparently mainly confined to the area south of the Wyville Thomson Ridge and hardly affected the Shetland area, as the northern part of the Faroe Channel was free of *S. serratodentata* in spring, but contained boreal forms such as *S. maxima*, *Eukrohnia hamata*, *Calanus hyperboreus* and *Metridia longa*, although these were mixed to some extent with *Rhincalanus*. By summer however the stream appeared to have broadened, particularly at the Faroe-Hebrides line when *Clio pyramidata* was found across almost the whole line in June and July, with an abundance of *D. gegenbauri* with some *S. fusiformis*. Other forms also present included *Lensia*, *Hippopodius*, *Clio cuspidata*, *S. planctonis*, *Travisopsis* and *Argyropelecus*. This exotic fauna is similar to, and probably

derived from the fauna found in March over deep water west of Barra where the above species were found with also *Rosacea*, *Chuniphyes*, *Vogtia*, *Arachnactis*, *S. macrocephala*, *Krohnitta subtilis* and *Eukronia fowleri*. During the summer little of the oceanic fauna penetrated into the northern North Sea. The fauna of Shetland to Fladen area had an unusually dense population of *Hybocodon prolifer* and on the eastern side of *Agalma elegans* was common with *Eucheta norvegica* in the Norwegian Deep. Nevertheless, to the west of the *Hybocodon prolifer* area, i.e. to the immediate east of Orkney and Moray Firth, the continued penetration

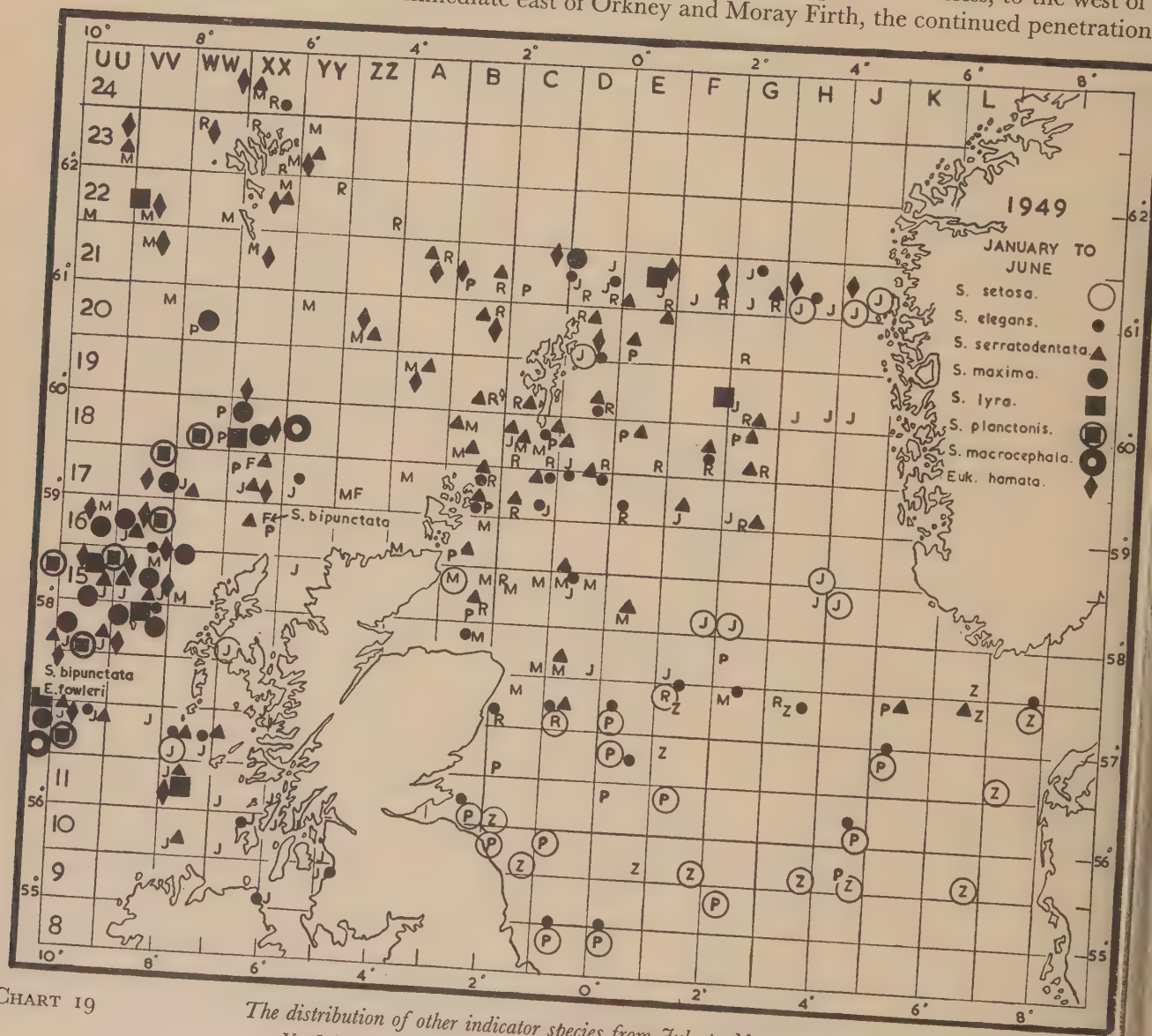


CHART 19

The distribution of other indicator species from July to November, 1950
Y=July, A=August, S=September, O=October, N=November.

Atlantic water via the Orkney passage is shown by the presence there of salps and doliolids and Rhincalanus in July and August.

Although these forms had penetrated so far by August the greatest concentration of oceanic species in the 1950 influx were still to be found west of the Faroe Channel and were in fact sampled west of Barra in August, and in great profusion in a cross section from the Hebrides across Rosemary and Lousy Banks to Iceland in September, with the greatest concentrations south-east of Lousy Bank. Although this oceanic fauna was still abundantly entering the Faroe Channel north of the Hebrides in November the more tolerant of the exotic forms were by then represented north of Shetland and many of them east of Shetland.

S. serratodentata, *S. lyra*, *S. maxima*, *Eukrohnia hamata*, *Dimophyes*, *Hippopodius*, *Agalma*, *Arachnactis*, *S. fusiformis*, *D. gegenbauri*, *Pleuromamma robusta*, *Rhincalanus*, *Eucalanus* and *Clio*. This fauna entering the North Sea via the north of Shetland late in the year, though of much the same composition as that entering the North Sea via Orkney in July and August, is quite distinct in its distribution, affecting the area east of Shetland and Fair Isle with little penetration south of 59°N. The other influx affected the Moray Firth and east Scottish area in July and August, and the more tolerant forms such as doliolids (not salps) penetrated into the Gut and as far south as 55°30'N in October, with some evidence of being also carried eastwards in the swirl as *Rhincalanus* was taken in October in J13b.

In contrast to 1949, when distinct streams each containing its characteristic fauna were found to be entering the Faroe Channel north and south of the Wyville Thomson Ridge, the stream appears to have been more homogeneous in 1950. Beginning as a weak influence in spring south of the Wyville Thomson Ridge only the incoming stream of organisms increased in dimension throughout the summer, reaching a maximum in autumn when the whole Faroe Channel seemed to contain the same type of fauna, the only difference being the gradual dropping out of the less tolerant forms as the influx carried the organisms more and more eastwards from their natural habitat both in space and time, coupled with a fall in temperature. It would thus appear that any juncture west of the British Isles must have occurred farther south than the Scottish research ships operated, as is suggested by the results from drift bottles liberated from weather ships. The more southerly location of the Atlantic current might increase the pressure at the southern entrance to the Irish Sea and would thus account for the displacement of Irish Sea water northwards through the North Channel taking with it *S. setosa* as has been suggested. There is a possible explanation of the west Scottish coast plankton distribution in 1950 which cannot, from the plankton, be more than suggested. With the almost direct easterly pressure of Atlantic water at the entrance to the Faroe Channel and the apparently limited flow into the North Sea, there may well have developed, in the second half of the year in particular, a south-going current carrying oceanic organisms southwards instead of the usual north-eastwards along the edge of the Continental Shelf west of Scotland, and between the mainland and Rockall. This current, if it existed, would tend to cause an anti-clockwise swirl at the southern entrance to the Minch and so account for *S. setosa* from the south being found west of Barra, whereas a north-easterly pressure from the ocean would tend to distribute *S. setosa* only to the Clyde and inshore waters of the Minch. This stream in the deep water between Barra and Rockall contained not only species such as salps, doliolids, siphonophores, *S. serratodentata*, *S. planctonis*, etc., but also the boreal species *Calanus hyperboreus* and *Metridia longa*, the latter in particular not being usually found even in the deep cold water of this part of the shelf. This is however merely a suggestion applying to 1950 which cannot apply in 1949.

It can thus be seen that the values of the plankton indicator method in tracing the actual paths of ocean currents are several.

1. It is a method of tracing the major paths in a given locality, giving "on the spot" information when the results from the more precise and conventional methods of the hydrographer may take time to analyse.
2. It can be used to give pointers when the conventional methods are open to alternative explanations or even to suggest that there may be alternative explanations.
3. It can be used to indicate small currents but possibly important ones ecologically, when the volume of water may not be enough to produce differences readily detectable on hydrographical examination.
4. It can at times suggest the final areas of dispersal of water which has become too diluted to be recognised by other methods.

THE FAIR ISLE PASSAGE

As a particular example of the use of plankton indicators in solving a specific problem, the question of the inflow of oceanic water through the passages between Shetland and Scotland can be considered. Prior to observations by Tait, it was generally considered that all the passages between Shetland and Scotland were open to the inflow of oceanic water flowing from west to east, but Tait (1930, 1931 and 1934) suggested from hydrographical evidence that these passages could not be so considered, and that no influx

occurred this way. He states that in 1932, at least, the passage between Shetland and Fair Isle was affected by Atlantic water from east to west, *i.e.* with water that had already come round the north of Shetland and this current is illustrated in his chart (1934, fig. 1). Fraser (1949a), studying the distribution of salps and doliolids in this area from 1920–39, thought that some of these indicator species entered the North Sea to the south of but not north of Fair Isle in the years 1920, 1924, 1925, 1928 and possibly 1929, and so

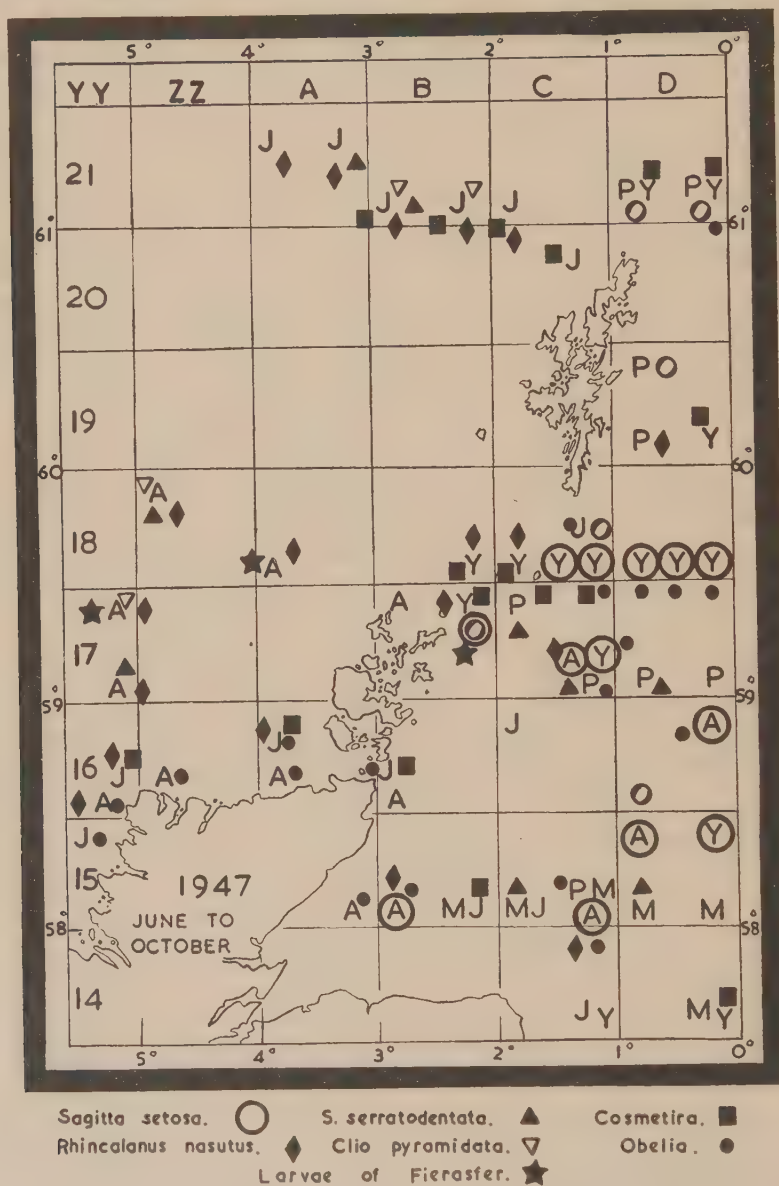


CHART 20.

The distribution of indicator species in the Fair Isle and surrounding areas from June to October, 1947

J=June, Y=July, A=August, O=October.

affected the Moray Firth area; in other years (1923, 1926, 1930 and 1935) no such invasion existed. He also found evidence in 1921, 1923, 1930 and 1935 to support Tait's suggestion of an east to west current north of Fair Isle. Tait (1949b, page 54), with reference to the year 1948, states: "There is some evidence also from drift bottles of influx to the north-western region through the passages between Shetland and Orkney, chiefly between Fair Isle and Orkney, and it is apparent that this influx extended considerably to the eastward and south-eastward of Orkney and well into the Moray Firth."

The Scottish plankton records from 1936 to 1950 most strongly support the deductions made from the distributions of the salps and doliolids from 1920–1939, *i.e.* that the current north of Orkney in the majority of the years, but not in all, carries water from the west of Orkney into the Moray Firth and sometimes to the east of the Moray Firth; water which contains oceanic species and which, therefore, contains oceanic elements, even though they may be diluted to a varying extent prior to their passage into the

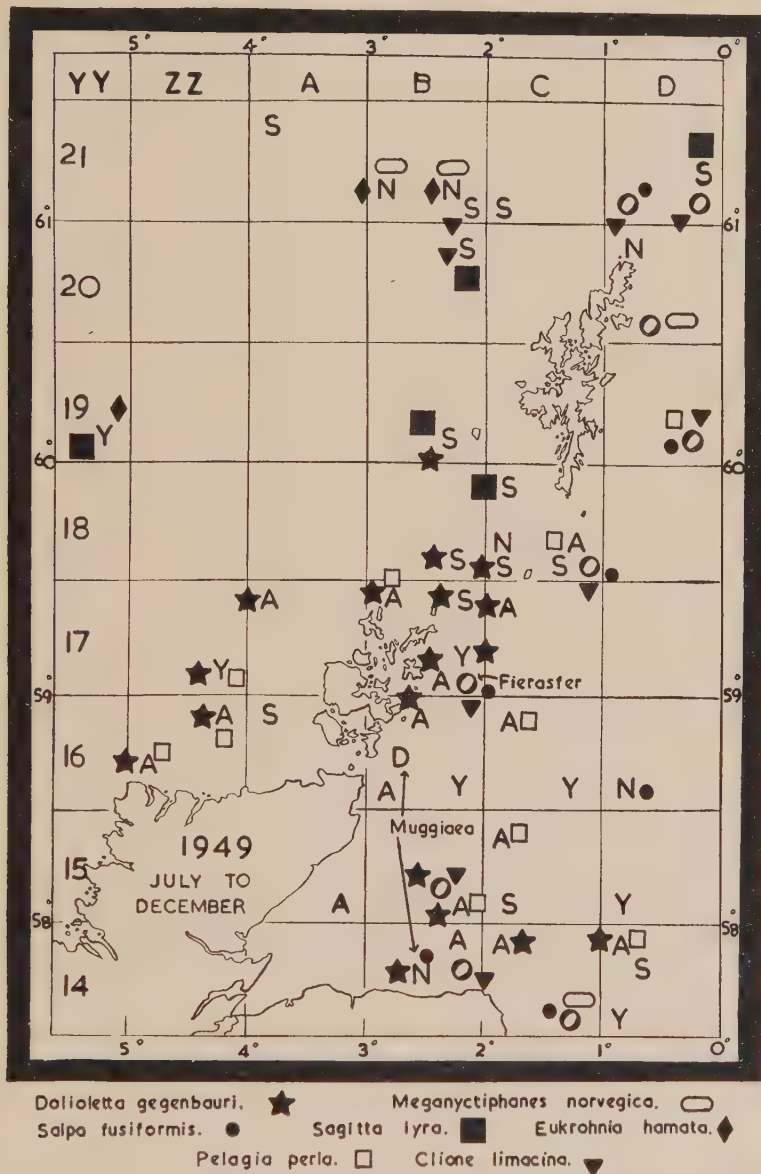


CHART 21.

The distribution of indicator species in the Fair Isle and surrounding areas from July to December, 1949

Y=July, A=August, S=September, O=October, N=November, D=December.

North Sea. Moreover, this current is strong enough to influence the ecology of the north-western North Sea and it does so some four to eight weeks earlier than the purer oceanic influx round the north of Shetland. The Orkney current can be in operation in years when the north of Shetland influx appears to be at a minimum. The years of marked Orkney influence since 1936 are 1939, 1947, 1948, 1949 and 1950; whilst those when the evidence was against such an influx were 1937 and 1946, the evidence for 1936 and 1938 being indecisive. Data on which these deductions are based have been already given in brief in the

descriptions of the years and some of the points illustrated on the charts. More detailed charts for 1947 and 1949, including a greater variety of species, are given to illustrate this particular theme more fully (Charts 20 and 21).

In addition to the tracing of movements and the dispersal of water of various origins, plankton indicators can be used in given localities to distinguish between water masses which differ ecologically. Kändler (1950) was able to show that in the Fehmarnbelt, at the entrance to the Baltic, the commercial fish population as well as the plankton could very largely be linked up with the entrance of sub-surface water of relatively high salinity from the Kattegat.

Adjacent areas of the sea often have different dominant plankton species, either of zooplankton or phytoplankton. When conditions favour rapid production of phytoplankton, one species of diatom may develop almost to the exclusion of others, whereas in a neighbouring area a different species develops, or perhaps a rich variety of species. The food value of the various phytoplankton species is likely to be different and, because of their shape, size or spinose nature their availability as food to various zooplankton species also differs, so that an important ecological difference is set up at the very start of the food chain, one which may have even more important developments later. It is clear that waters of different origin, as discussed above, are likely to have chemical compositions sufficiently different to produce such changes. However, differences in plankton content also exist in quite small local areas which cannot be accounted for by such a hypothesis. What causes these primary differences is a matter of conjecture at present, though Lucas (1947, 1949b) has some very significant suggestions to make. As the study of the chemistry of the less common elements of sea water is still somewhat in its infancy, it is unlikely that these differences will be chemically apparent for some time yet, but as suggested on page 15 it may not at this stage be necessary to define them in chemical or physical terms.

Because different living organisms utilise different materials and secrete different substances into their environment during their metabolic processes and when dead become broken down into different products it is only to be expected that food chains will vary and that adjacent waters of almost identical original composition are liable to produce a greatly different end product of carnivorous forms, including eventually the pelagic and bottom-living commercial fish themselves. The effect on the commercial fishery may be due not only to differing food composition or value, but also to the behaviour of the fish in deliberately avoiding obnoxious elements or by being attracted to suitable environments. To quote a single example herring are known to avoid dense patches of phytoplankton in their migratory movements, and when feeding tend to remain in areas of good food supply; (See Hardy, *et al.*, 1936, and the authors quoted therein).

Work on the effect of the differences between water masses from varying localities on the development of planktonic larvæ by Wilson (1951) has given a valuable lead to the understanding of the importance of these small differences, and it is significant to note here that Wilson used the presence of *Sagitta elegans* or *S. setosa* as the means of assessing the character of the water samples to be used for his work.

The sensitivity of *S. elegans elegans* to the presence of a minute quantity of some, presumably, chemical substance as yet unknown is probably one of the most important single factors that have been discovered in relation to marine indicator species. In this paper and previously (Fraser, 1937 and 1939) *Sagitta elegans* has been associated with the mixing of coastal and oceanic waters. Clarke, Pierce and Bumpus (1943) associated the thriving abundance of *S. elegans* on Georges Bank with the relative permanence of the water mass coupled with some unknown influence from the bottom or shore. Russell (1936a and b, 1937, etc.) associated his "south-western" water containing *S. elegans* with a relatively high phosphate content. Cooper (1951) has advanced this by his work on the chemical properties of the water associated with Wilson's experiments. He suggests that phosphate is regenerated from suspended detritus bottom mud or ooze in such areas as Labadie Bank, where *Sagitta elegans* is common, but he points out that this enrichment is unlikely to be confined to phosphate, and other growth-promoting substances are likely to accompany it. The presence of this species gives a rapid indication of the presence of the best type of water, not only for the growth of planktonic larvæ as shown by Wilson, but for the development of larval fish popula-

tions (Russell, 1936a, 1937, 1939). In the northern North Sea it is associated with plankton rich in protein and oil that could mean greater production of other forms, including adult as well as larval fish, which are dependent, or ultimately dependent on the zooplankton as the source of their food supply. Only the fringe of this field of research has as yet been touched and it is hoped that further work on these lines, both in Aberdeen and elsewhere, will yield information that may be of still greater value in fishery research.

SUMMARY

The indicator value of the Chætognatha in the Scottish and adjacent areas is discussed. This group is unique in that the few genera and species which occur in this area have each a somewhat different natural habitat. To be useful indicators, organisms must be readily identifiable, and in order to facilitate quick but reliable identifications new descriptions of the planktonic species are given, based more on their general appearance in the collections and less on characters that require close investigation. A key, on this basis, is given for all the species likely to be found in west European seas, and for greater convenience in a less widespread area a shorter key to those species occurring in the North Sea is also included. The descriptions are supplemented by short references to confirmatory characters and by a double set of photographs, one giving the natural appearance and the other retouched to emphasise the features used in identification.

The hydrography of the area in each of the years 1936–1939 and 1946–1950 is summarised from the papers published by hydrographic experts and this is then correlated with the description of the Chætognatha taken in the plankton by the Scottish Home Department's research vessels. These correlations are also considered together with the distribution of other indicator organisms which have varying degrees of tolerance to differences from their natural habitats, and a great degree of agreement with the hydrographers' opinions is shown. It is suggested that the plankton indicator method of approach as an aid in solving hydrographic problems can be of special value in (1) giving "on the spot" information; (2) giving pointers when the conventional methods are open to alternative explanations; (3) indicating small currents when the volume of water may be too small to be detected readily by hydrographic examination; and (4) suggesting the final areas of dispersal of water which has become too dilute to be recognised by other methods.

These uses have been applied to the question of the influx of Atlantic water through the Fair Isle Passage and they confirm Tait's theory that the passage between Fair Isle and Shetland is not to be considered as an inlet for Atlantic water. The plankton indicators do, however, suggest that in some years a current round the immediate north of Orkney brings water that originally contained oceanic elements into the northern Moray Firth with dispersal towards the Fraserburgh area, and that when this occurs this water affects that area 4–8 weeks earlier than the main inflow round the north of Shetland.

It is further suggested that the plankton indicators may be used not only as an aid in solving some of the hydrographic problems but also to help in understanding the very complex factors through which the varying hydrographic conditions affect the biomass and eventually the commercial fisheries.

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EXPLANATION OF PLATES

Photographs of fifteen species of Chætognaths from North Atlantic waters are shown in Plates I, II and III. The left hand plates are direct photographs of formalin preserved specimens seen on a black background, to show their natural appearance under these conditions. Opposite each is a duplicate photograph with numbered figures, and retouched to emphasize some of the diagnostic characters which are often difficult to see in unstained specimens and so are liable to be absent in a photograph or lost in the process of reproduction.

PLATE I

- Fig. 1. *Sagitta setosa*.
- Fig. 2. *Sagitta elegans*.
- Fig. 3. *Sagitta serratodentata*.
- Fig. 4. *Eukrohnia hamata*.

PLATE II

- Fig. 5. *Sagitta hexaptera*.
- Fig. 6. *Sagitta maxima*.
- Fig. 7. *Sagitta lyra*.
- Fig. 8. *Sagitta enflata*.
- Fig. 9. *Sagitta Planctonis*.
- Fig. 10. *Sagitta macrocephala*.

PLATE III

- Fig. 11. *Sagitta bipunctata*.
 - Fig. 12. *Sagitta friderici*.
 - Fig. 13. *Sagitta tenuis*, specimen from Florida.
 - Fig. 14. *Eukrohnia fowleri*.
 - Fig. 15. *Krohnitta subtilis*.
- } specimens from Morocco.

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